(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
7 February 2002 (07.02.2002)

PCT

(10) International Publication Number
WO 02/10589 A1

(51) International Patent Classification[7]: F03D 11/04, B63B 21/50

(21) International Application Number: PCT/IE01/00097

(22) International Filing Date: 27 July 2001 (27.07.2001)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
S2000/0601 27 July 2000 (27.07.2000) IE
S2001/0627 29 June 2001 (29.06.2001) IE

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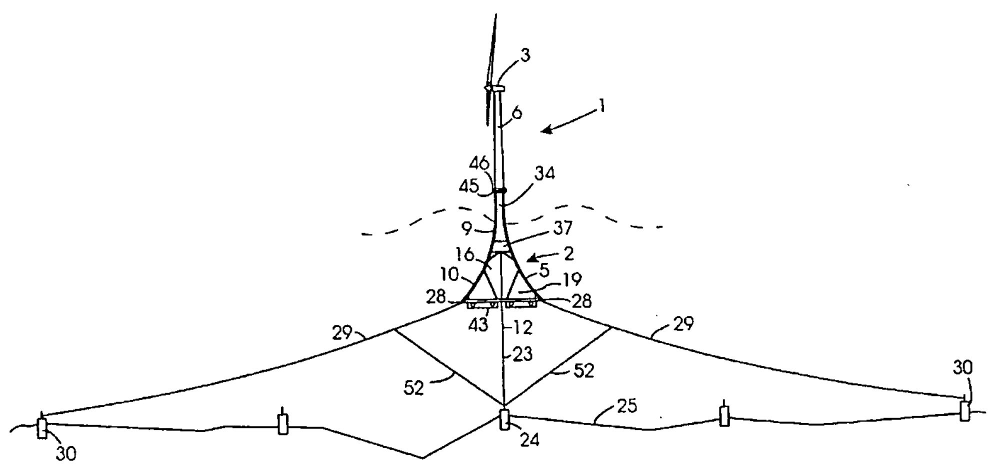
(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: FLOATING STRUCTURE FOR MOUNTING A WIND TURBINE OFFSHORE



(57) Abstract: A wind powered generator (1) for locating offshore comprises a semi-submersible structure (5) with a mast (6) extending upwardly therefrom for carrying a wind turbine (3). A primary buoyancy chamber (16) is formed in the semi-submersible structure (5), and a primary anchor cable (23) is secured to the semi-submersible structure (5) in the primary buoyancy chamber (16) by a primary connecting bracket (22). The primary anchor cable (23) extends directly downwardly to a primary anchorage (24) in the sea bed (25) for anchoring the semi-submersible structure (5). Additionally, a winching mechanism (not shown) is provided for winching the semi-submersible structure (5) downwardly on the primary anchor cable (23) in the water against the upward buoyancy force acting on the semi-submersible structure (5) for raising the centre of flotation of the semi-submersible structure (5), for in turn increasing the righting moment acting on the semi-submersible structure for returning the semi-submersible structure (5) to its equilibrium flotation state in the event of the semi-submersible structure (5) tilting from the vertical.

WO 02/10589 A1

FLOATING STRUCTURE FOR MOUNTING A WIND TURBINE OFFSHORE

The present invention relates to a floatable structure for mounting a wind turbine offshore, and the invention also relates to a method for mounting a wind turbine offshore and to a wind farm containing wind turbines mounted offshore.

With the ever increasing cost of fossil fuels and the attendant environmental damage resulting from energy generation from fossil fuels, and the potential danger associated with generation of energy from nuclear power, it is desirable that increasingly higher proportions of energy be generated from renewable energy sources. Wind being one of the primary renewable energy sources, it is desirable that maximum utilisation should be made of wind energy in the generation of electricity and other forms of energy. However, wind powered generators suffer from a number of disadvantages. In general, wind powered generators comprise a mast with a wind turbine mounted on top thereof. The wind energy may be converted directly to electricity by the wind turbine at the top of the mast, or alternatively, a drive transmission arrangement may be provided within the core of the mast for transmitting drive from the wind turbine to a electricity generator located at the bottom or towards the bottom of the mast. Typically, such wind turbines are horizontal axis turbines, and in order to efficiently capture sufficient energy from the wind, in general, are provided with relatively long blades. Because of the relative length of the turbine blades, and furthermore, the need to locate the turbine blades in an uninterrupted air stream, such turbines are generally mounted on top of relatively high masts. Such masts tend to be relatively unsightly, and are particularly unsightly when a plurality of such masts with their corresponding wind turbines are mounted relatively closely together in what is typically referred to as a wind farm. As well as being relatively unsightly, wind turbines tend to create a significant amount of noise. This is undesirable. Accordingly, such wind turbines are unsuitable for mounting adjacent centres of population, and because of their relatively undesirable appearance, are unsuitable for mounting in remote areas, which, in general, tend to

be beauty spots.

Attempts to locate such wind turbines, and indeed, farms of wind turbines offshore have been made, however, due to the relatively hazardous environment in offshore locations, the location of wind farms offshore so far have had limited success. In general, wind turbines which are located offshore are mounted on top of a mast which is secured in the sea bed and extends upwardly therefrom. Thus, because the mast extends upwardly from the sea bed, such constructions of wind turbines and masts are suitable only for relatively shallow waters, which in general are found only relatively close to the shore. In general, shorelines are considered to be high amenity areas, and thus, in general, the siting of wind turbines relatively close to the shore is not desirable, and in general, is not permissible. Furthermore, wind speeds and direction tend to fluctuate more relatively close to the shoreline, than well out from the shoreline, for example, in relatively deep waters. Thus, for the above reasons, known methods for locating wind turbines offshore in general are unsatisfactory.

There is therefore a need for a floatable structure which is suitable for locating a wind turbine offshore. There is also a need for a method for locating a wind turbine offshore, as is there a need for an offshore wind farm.

The present invention is directed towards providing such a floatable structure, a method for locating a wind turbine offshore and a wind farm.

According to the invention there is provided a method for locating a wind turbine offshore characterised in that the method comprises the steps of locating the wind turbine on a mast extending upwardly from a floatable semi-submersible structure, anchoring the semi-submersible structure by a primary ligature extending in a generally downwardly direction from the semi-submersible structure, and urging the semi-submersible structure downwardly in the water by the primary ligature below its normal flotation level against an upwardly directed buoyancy force acting on the semi-submersible structure for raising the centre of flotation of the semi-submersible

structure for in turn increasing the righting moment acting on the semi-submersible structure for returning the semi-submersible structure to its equilibrium flotation state.

In one embodiment of the invention the semi-submersible structure is anchored by the primary ligature to a primary anchorage in the sea bed.

In another embodiment of the invention the semi-submersible structure defines a main central geometric axis, which extends vertically when the semi-submersible structure is in its equilibrium flotation state, and the primary ligature is connected to the semi-submersible structure on the main central axis. Preferably, the primary ligature coincides with the main central axis of the semi-submersible structure. Advantageously, the semi-submersible structure is urged downwardly by the primary ligature so that the centre of flotation is above the centre of gravity of the semi-submersible structure.

In one embodiment of the invention the semi-submersible structure is urged downwardly by the primary ligature so that the centre of flotation is above the centre of gravity of the combined semi-submersible structure, the mast and the wind turbine. Preferably, the semi-submersible structure is urged downwardly by the primary ligature so that the relative position of the centre of flotation and the centre of gravity is such as to provide a sufficient righting moment acting through the centre of flotation for returning the semi-submersible structure to its equilibrium flotation state. Advantageously, the semi-submersible structure is urged downwardly by the primary ligature so that the righting moment acting through the centre of flotation for returning the semi-submersible structure to its equilibrium flotation state is sufficient for returning the semi-submersible structure to its equilibrium state on the semi-submersible structure tilting to an extent that the main central axis of the semi-submersible structure falls outside a vertically extending cone angle not greater than 12°. Preferably, the cone angle does not exceed 8°. Ideally, the cone angle does not exceed 5°.

In one embodiment of the invention the semi-submersible structure is urged

downwardly by the primary ligature so that the point of connection at which the primary ligature is connected to the semi-submersible structure lies between the centre of flotation and the centre of gravity of the semi-submersible structure.

In another embodiment of the invention the semi-submersible structure is further anchored by a plurality of secondary ligatures extending in a generally downwardly direction from the semi-submersible structure for limiting movement of the semi-submersible structure from its equilibrium flotation state, the secondary ligatures being spaced apart circumferentially around and radially from the main central axis. Preferably, the secondary ligatures are equi-spaced apart circumferentially around the main central axis.

In one embodiment of the invention each secondary ligature is anchored to the sea bed by a corresponding secondary anchorage.

In another embodiment of the invention each secondary ligature is resiliently connected to one of the semi-submersible structure and the sea bed for damping movement of the semi-submersible structure from its equilibrium flotation state. Preferably, each secondary ligature is resiliently connected to the semi-submersible structure.

In one embodiment of the invention at least three secondary ligatures are provided. Preferably, at least four secondary ligatures are provided.

In one embodiment of the invention the secondary ligatures are connected to the semi-submersible structure at connection points on a common pitch circle. Preferably, the secondary ligatures are connected to the semi-submersible structure adjacent a periphery thereof. Advantageously, the secondary ligatures are connected to the semi-submersible structure adjacent an outer periphery thereof.

In a further embodiment of the invention the semi-submersible structure is further anchored by a plurality of auxiliary ligatures connected to the semi-submersible

structure at locations spaced apart circumferentially around the main central axis, the respective auxiliary ligatures extending in a generally downwardly, radially outwardly direction of the semi-submersible structure.

In another embodiment of the invention the respective auxiliary ligatures are connected to the semi-submersible structure at equi-spaced apart auxiliary locations circumferentially around the main central axis.

In one embodiment of the invention each auxiliary ligature extends downwardly, radially outwardly from the semi-submersible structure at an angle to the vertical in the range of 1° to 89° and continues in a cathenary towards a corresponding radially outwardly spaced apart auxiliary anchorage in the sea bed spaced apart radially outwardly from the primary anchorage. Preferably, each auxiliary ligature extends downwardly, radially outwardly from the semi-submersible structure at an angle to the vertical in the range of 60° to 80°. Ideally, each auxiliary ligature extends downwardly, radially outwardly from the semi-submersible structure at an angle to the vertical of approximately 70°.

In one embodiment of the invention the auxiliary ligatures are connected to the semi-submersible structure at connection points on a common pitch circle. Advantageously, the auxiliary ligatures are connected to the semi-submersible structure adjacent a periphery thereof. Preferably, the auxiliary ligatures are connected to the semi-submersible structure adjacent an outer periphery thereof.

In one embodiment of the invention a primary buoyancy chamber is located in the semi-submersible structure, the primary buoyancy chamber defining a central geometric axis coinciding with the main central axis of the semi-submersible structure. Preferably, the primary ligature extends into the primary buoyancy chamber and is connected to the semi-submersible structure within the primary buoyancy chamber. Advantageously, a communicating opening is provided in the bottom of the semi-submersible structure to the primary buoyancy chamber for accommodating the primary ligature into the primary buoyancy chamber. Ideally, the

primary ligature is connected to the semi-submersible structure in the primary buoyancy chamber at the top dead centre of the primary buoyancy chamber.

In one embodiment of the invention compressed air is pumped into the primary buoyancy chamber for expelling water therefrom through the communicating opening for increasing the buoyancy of the semi-submersible structure.

In another embodiment of the invention ballast is applied to the semi-submersible structure for ballasting the semi-submersible structure. Preferably, the ballast is applied to the lower end of the semi-submersible structure. Advantageously, the ballast is applied circumferentially around the main central axis. Ideally, the ballast is radially spaced apart from the main central axis.

In one embodiment of the invention the mast defines a geometric central axis, and is mounted on the semi-submersible structure with its central axis coinciding with the central axis of the semi-submersible structure. In another embodiment of the invention the turbine is mounted on top of the mast. In one embodiment of the invention the turbine is a horizontal axis turbine. Alternatively, the turbine is a vertical axis turbine.

In one embodiment of the invention the turbine drives an electrical generator for generating electricity. Preferably, the electrical generator is located adjacent the turbine. Advantageously, the electrical generator is located in the semi-submersible structure, and a drive transmission means is provided between the turbine and the electrical generator.

Additionally the invention provides a floatable structure for carrying and locating a wind turbine offshore, the floatable structure comprising a semi-submersible structure having a primary buoyancy chamber, and comprising a mounting means located thereon for mounting a mast extending upwardly therefrom for carrying the wind turbine thereon, and a primary connecting means for connecting a primary ligature to the semi-submersible structure with the primary ligature extending in a

generally downwardly direction therefrom for anchoring the semi-submersible structure and for urging the semi-submersible structure downwardly in the water against an upwardly directed buoyancy force acting thereon for raising the centre of flotation of the semi-submersible structure for in turn increasing the righting moment acting on the semi-submersible structure for returning the semi-submersible structure to its equilibrium flotation state.

In one embodiment of the invention the semi-submersible structure defines a main central geometric axis which extends vertically when the semi-submersible structure is in its equilibrium flotation state, and the primary connecting means is located on the main central axis of the semi-submersible structure.

In another embodiment of the invention the primary connecting means connects the primary ligature to the semi-submersible structure to extend in a generally downwardly direction to a primary anchorage in the sea bed.

In another embodiment of the invention the centre of gravity of the semi-submersible structure is located so that when the semi-submersible structure is urged downwardly by the primary ligature the centre of flotation is above the centre of gravity.

In another embodiment of the invention the centre of gravity of the semi-submersible structure is below the centre of flotation of the semi-submersible structure when the semi-submersible structure is freely floating.

Preferably, the centre of gravity and the centre of flotation of the semi-submersible structure lie on the main central axis of the semi-submersible structure.

Advantageously, the primary connecting means is located intermediate the centre of gravity and the centre of flotation of the semi-submersible structure when the semi-submersible structure is urged downwardly in the water by the primary ligature.

In one embodiment of the invention the centre of flotation is above the centre of gravity by an amount sufficient to provide a righting moment acting through the centre of flotation for returning the semi-submersible structure to its equilibrium flotation state. Preferably, the centre of flotation is above the centre of gravity of the semi-submersible structure by an amount so that the righting moment acting through the centre of flotation is sufficient for returning the semi-submersible structure to its equilibrium flotation state when the semi-submersible structure has tilted from its equilibrium flotation state with its main central axis lying outside a vertical cone angle not exceeding 12°. Advantageously, the centre of flotation is above the centre of gravity of the semi-submersible structure by an amount so that the righting moment acting through the centre of flotation is sufficient for returning the semi-submersible structure to its equilibrium flotation state when the semi-submersible structure has tilted from its equilibrium flotation state with its main central axis lying outside a vertical cone angle not exceeding 8°. Ideally, the centre of flotation is above the centre of gravity of the semi-submersible structure by an amount so that the righting moment acting through the centre of flotation is sufficient for returning the semi-submersible structure to its equilibrium flotation state when the semi-submersible structure has tilted from its equilibrium flotation state with its main central axis lying outside a vertical cone angle not exceeding 5°.

In one embodiment of the invention a communicating opening in the lower end of the semi-submersible structure is provided to the primary buoyancy chamber for accommodating the primary ligature into the primary buoyancy chamber. Preferably, the primary connecting means is located in the primary buoyancy chamber. Advantageously, the primary connecting means is located at the top dead centre of the primary buoyancy chamber. Ideally, the communicating opening is adapted for accommodating water therethrough into and out of the primary buoyancy chamber for altering the buoyancy of the semi-submersible structure.

In one embodiment of the invention the diameter of the communicating opening to the primary buoyancy chamber is such that the semi-submersible structure engages the primary ligature at the communicating opening when the semi-submersible

structure tilts for causing the semi-submersible structure to tilt about the primary ligature adjacent the communicating opening.

In another embodiment of the invention the diameter of the communicating opening is slightly greater than the diameter of the primary ligature for accommodating water into and out of the primary buoyancy chamber past the primary ligature.

In one embodiment of the invention a communicating port is provided to the primary buoyancy chamber for facilitating delivery of a buoyancy medium to and exhausting the buoyancy medium from the primary buoyancy chamber for altering the buoyancy of the semi-submersible structure. Preferably, the communicating port is adapted for accommodating air into and from the primary buoyancy chamber.

In one embodiment of the invention a ballast receiving means is provided in the semi-submersible structure for receiving ballast for ballasting the semi-submersible structure and for altering the buoyancy of the semi-submersible structure. Advantageously, the ballast receiving means extends circumferentially around the main central axis. Preferably, the ballast receiving means is radially spaced apart from the main central axis. Ideally, the ballast receiving means comprises a ballast chamber.

In one embodiment of the invention a plurality of ballast chambers are located around the main central axis.

In another embodiment of the invention a means is provided for flooding each ballast chamber.

In a further embodiment of the invention the ballast receiving means comprises a ballast engaging means for receiving ballast members. Preferably, the ballast engaging means is located beneath the ballast chambers.

In another embodiment of the invention a secondary buoyancy chamber is located

above the primary buoyancy chamber and is isolated from the primary buoyancy chamber. Preferably, the secondary buoyancy chamber extends above the waterline of the semi-submersible structure when the semi-submersible structure is freely floating. Advantageously, the secondary buoyancy chamber is located to be below the waterline when the semi-submersible structure is urged downwardly in the water by the primary ligature.

In one embodiment of the invention a plurality of secondary connecting means are provided for connecting respective secondary ligatures extending in a generally downwardly direction from the semi-submersible structure for further anchoring the semi-submersible structure and for limiting movement of the semi-submersible structure from its equilibrium flotation state, the secondary connecting means being spaced apart circumferentially around the main central axis of the semi-submersible structure and radially therefrom.

In another embodiment of the invention the secondary connecting means connect the respective secondary ligatures to the semi-submersible structure with the secondary ligatures extending in a generally downwardly direction to corresponding secondary anchorages in the sea bed. Preferably, the secondary connecting means are equi-spaced apart circumferentially around the main central axis of the semi-submersible structure. Advantageously, the respective secondary connecting means are located on a common pitch circle.

In one embodiment of the invention the respective secondary connecting means are located adjacent a periphery of the semi-submersible structure.

In another embodiment of the invention the respective secondary connecting means are located adjacent an outer periphery of the semi-submersible structure.

In another embodiment of the invention each secondary connecting means comprises a resilient mounting for resiliently connecting the corresponding secondary ligature to the semi-submersible structure for damping oscillating

movement of the semi-submersible structure from its equilibrium flotation state about the vertical. Preferably, each resilient mounting means comprises a compression spring carrying a mounting member for securing the corresponding secondary ligature thereto so that upward movement of the semi-submersible structure adjacent the resilient mounting means causes compression of the compression spring.

In another embodiment of the invention a plurality of auxiliary connecting means are provided for connecting respective auxiliary ligatures to the semi-submersible structure for further anchoring and stabilising the semi-submersible structure, the auxiliary connecting means being located at spaced apart intervals circumferentially around the main central axis of the semi-submersible structure and radially spaced apart therefrom. Preferably, the auxiliary connecting means connect the respective auxiliary ligatures to the semi-submersible structure with the auxiliary ligatures extending in a generally downwardly, radially outward direction to corresponding auxiliary anchorages in the sea bed. Advantageously, the respective auxiliary connecting means are equi-spaced apart circumferentially around the main central axis of the semi-submersible structure.

In one embodiment of the invention the respective auxiliary connecting means are located on a common pitch circle. Advantageously, the respective auxiliary connecting means are located adjacent a periphery of the semi-submersible structure. Preferably, the respective auxiliary connecting means are located adjacent an outer periphery of the semi-submersible structure.

In one embodiment of the invention the respective auxiliary connecting means are provided for connecting the corresponding auxiliary ligatures to the semi-submersible structure with the auxiliary ligatures extending in a generally downwardly radially outward direction from the semi-submersible structure.

In another embodiment of the invention the respective auxiliary connecting means are provided for connecting the auxiliary ligatures to the semi-submersible structure

with the respective auxiliary ligatures extending from the semi-submersible structure at an angle to the vertical in the range of 1° to 89°. Preferably, the respective auxiliary connecting means are provided for connecting the auxiliary ligatures to the semi-submersible structure with the respective auxiliary ligatures extending from the semi-submersible structure at an angle to the vertical in the range of 60° to 80°. Advantageously, the respective auxiliary connecting means are provided for connecting the auxiliary ligatures to the semi-submersible structure with the respective auxiliary ligatures extending from the semi-submersible structure at an angle to the vertical of approximately 70°.

In one embodiment of the invention the auxiliary connecting means are located towards the bottom of the semi-submersible structure.

In another embodiment of the invention the auxiliary connecting means are located for connecting the respective auxiliary ligatures to the semi-submersible structure so that the auxiliary ligatures define a cathenary.

In a further embodiment of the invention the respective auxiliary connecting means are located at a level above the respective secondary connecting means.

In one embodiment of the invention an auxiliary buoyancy chamber extends around the secondary buoyancy chamber.

Preferably, the transverse cross-section of the semi-submersible structure when viewed in plan adjacent the average wave height when the semi-submersible structure is urged downwardly in the water by the primary ligature is relatively narrow for minimising resistance to waves.

In one embodiment of the invention the semi-submersible structure comprises the primary ligature.

In another embodiment of the invention the semi-submersible structure comprises

the secondary ligatures.

In a further embodiment of the invention the semi-submersible structure comprises the auxiliary ligatures.

In a still further embodiment of the invention a component chamber is located in the semi-submersible structure for accommodating an electrical generator and/or control apparatus for the electrical generator. Preferably, the component chamber is located between the primary and secondary buoyancy chambers.

In one embodiment of the invention the mounting means for mounting the mast on the semi-submersible structure is located above the waterline of the semi-submersible structure. Preferably, the mounting means for mounting the mast on the semi-submersible structure is located above the waterline of the semi-submersible structure when the semi-submersible structure is urged downwardly by the primary ligature in the water.

In another embodiment of the invention the mast is mounted on the semi-submersible structure. Preferably, the wind turbine is mounted on the mast, and preferably, the wind turbine is mounted on the top of the mast. In one embodiment of the invention the wind turbine is a horizontal axis wind turbine. Alternatively, the wind turbine is a vertical axis wind turbine.

Further the invention provides a floatable structure for locating a wind turbine offshore, the floatable structure comprising a semi-submersible structure having a primary buoyancy chamber, and comprising a mounting means located thereon for mounting a mast extending upwardly therefrom for carrying the wind turbine thereon, the semi-submersible structure defining a main geometric central axis and being floatable in an equilibrium flotation state with the main central axis extending generally vertically, and at least two secondary connecting means spaced apart circumferentially around the main central axis and radially therefrom for connecting the semi-submersible structure to respective corresponding secondary ligatures

extending generally downwardly from the semi-submersible structure for anchoring the semi-submersible structure and for urging the semi-submersible structure downwardly in the water against an upwardly directed buoyancy force acting on the semi-submersible structure for raising the centre of flotation of the semi-submersible structure for in turn increasing the righting moment acting on the semi-submersible structure for returning the semi-submersible structure to its equilibrium flotation state.

In one embodiment of the invention a plurality of the secondary connecting means are provided for connecting a plurality of the respective secondary ligatures extending in a generally downwardly direction from the semi-submersible structure for further anchoring the semi-submersible structure, the secondary connecting means being spaced apart circumferentially around the main central axis of the semi-submersible structure and radially therefrom. Preferably, the secondary connecting means are equi-spaced apart circumferentially around the main central axis of the semi-submersible structure. Advantageously, the respective secondary connecting means are located on a common pitch circle.

In one embodiment of the invention the respective secondary connecting means are located adjacent a periphery of the semi-submersible structure. Preferably, the respective secondary connecting means are located adjacent an outer periphery of the semi-submersible structure.

In one embodiment of the invention each secondary connecting means comprises a resilient mounting for resiliently connecting the corresponding secondary ligature to the semi-submersible structure for damping oscillating movement of the semi-submersible structure from its equilibrium flotation state about the vertical. Preferably, each resilient mounting means comprises a compression spring carrying a mounting member for securing the corresponding secondary ligature thereto so that upward movement of the semi-submersible structure adjacent the resilient mounting means causes compression of the compression spring.

In one embodiment of the invention each secondary connecting means connects the

corresponding secondary ligature to the semi-submersible structure with the secondary ligature extending in a generally downwardly direction to corresponding secondary anchorage in the sea bed.

In another embodiment of the invention a plurality of auxiliary connecting means are provided for connecting respective auxiliary ligatures to the semi-submersible structure for further anchoring the semi-submersible structure, the auxiliary connecting means being located at spaced apart intervals circumferentially around the main central axis of the semi-submersible structure and radially spaced apart therefrom.

Advantageously, the respective auxiliary connecting means are equi-spaced apart circumferentially around the main central axis. Ideally, the respective auxiliary connecting means are located on a common pitch circle. Preferably, the respective auxiliary connecting means are located adjacent a periphery of the semi-submersible structure. Preferably, the respective auxiliary connecting means are located adjacent an outer periphery of the semi-submersible structure.

In one embodiment of the invention the auxiliary connecting means are provided for connecting the corresponding auxiliary ligatures to the semi-submersible structure with the auxiliary ligatures extending in a generally downwardly, radially outward direction from the semi-submersible structure.

In a further embodiment of the invention the respective auxiliary connecting means are provided for connecting the auxiliary ligatures to the semi-submersible structure with the respective secondary ligatures extending from the semi-submersible structure at an angle to the vertical in the range of 1° to 89°. Preferably, the respective auxiliary connecting means are provided for connecting the auxiliary ligatures to the semi-submersible structure with the respective auxiliary ligatures extending from the semi-submersible structure at an angle to the vertical in the range of 60° to 80°. Advantageously, the respective auxiliary connecting means are provided for connecting the auxiliary ligatures to the semi-submersible structure with

the respective secondary ligatures extending from the semi-submersible structure at an angle to the vertical of approximately 70°.

In one embodiment of the invention the auxiliary connecting means are located towards the bottom of the semi-submersible structure. In another embodiment of the invention the auxiliary connecting means are located for connecting the respective auxiliary ligatures extending from the semi-submersible structure to define a cathenary.

In one embodiment of the invention each auxiliary connecting means connects the corresponding auxiliary ligature to the semi-submersible structure to extend in a generally downwardly radially outward direction to a corresponding auxiliary anchorage in the sea bed.

In another embodiment of the invention the semi-submersible structure comprises the secondary ligatures. In a further embodiment of the invention the semi-submersible structure comprises the auxiliary ligatures.

Further the invention provides a wind power energy converter for converting wind energy to usable power comprising the semi-submersible structure according to the invention, the semi-submersible structure being anchored by the primary ligature extending in a generally downwardly direction, and being urged downwardly in the water by the primary ligature against the upward direction of the buoyancy force acting on the semi-submersible structure, for raising the centre of flotation of the semi-submersible structure for in turn increasing the righting moment acting on the semi-submersible structure for returning the semi-submersible structure to its equilibrium flotation state, a mast extending upwardly from the semi-submersible structure, and a wind turbine mounted on the mast for providing usable power.

In one embodiment of the invention an electrical generator is operably coupled to the wind powered turbine for generating electricity.

The invention also provides a wind farm comprising a plurality of wind energy converters according to the invention for converting wind energy to usable energy, the wind energy converters being located at spaced apart intervals offshore.

In one embodiment of the invention the wind energy converters are located in a plurality of spaced apart rows, each row comprising a plurality of wind energy converters.

In another embodiment of the invention the wind energy converters of alternate rows are offset from the wind energy converters of their adjacent rows.

In a further embodiment of the invention the wind energy converters of alternate rows are located substantially halfway between the wind energy converters of their adjacent rows in an offset state.

Preferably, the rows of wind energy converters are equi-spaced apart from each other.

The advantages of the invention are many. A particularly important advantage of the invention is that the floatable structure according to the invention permits the location of wind turbines and wind energy converters offshore in relatively deep water, and thus such wind turbines and wind energy converters may be located well offshore, and in particular, out of sight from the shoreline.

A further advantage of the floatable structure according to the invention is that it provides a particularly stable structure on which to mount a wind turbine. By virtue of the fact that the structure is urged downwardly in the water by a primary ligature against the upwardly directed buoyancy force acting on the semi-submersible structure, the centre of flotation of the semi-submersible structure is raised, and this in turn increases the righting moment on the semi-submersible structure for returning the semi-submersible structure to its equilibrium flotation state in the event that it tilts from the vertical from its equilibrium flotation state. By ensuring that the centre of

flotation is above the centre of gravity, the resultant of the moments acting through the centre of gravity and through the centre of flotation is a righting moment for righting the semi-submersible structure back into its equilibrium flotation state. By urging the semi-submersible structure downwardly in the water by the primary ligature so that the primary connecting means for connecting the primary ligature to the semi-submersible structure is located between the centre of flotation and the centre of gravity the resultant of the moments acting through the centre of gravity and the centre of flotation is a righting moment for returning the semi-submersible structure to its equilibrium flotation state.

By locating the primary connecting means for the primary ligature on the main central axis of the semi-submersible structure which extends through the centre of gravity and the centre of flotation, a particularly stable structure is provided.

Other advantages of the invention are achieved by providing the secondary connecting means for connecting the secondary ligatures to the semi-submersible structure, and a particular advantage is achieved by resiliently connecting the secondary ligatures to the secondary connecting means in that the resilient connections tend to damp oscillating movement of the semi-submersible structure about a vertically extending axis. The provision of the auxiliary ligatures further facilitates in stabilising the semi-submersible structure.

A further advantage of the invention is provided by the provision of the communicating port and the communicating opening to and from the primary buoyancy chamber in that pumping air, typically, compressed air into the primary buoyancy chamber for expelling water from the primary buoyancy chamber for varying the buoyancy of the semi-submersible structure is facilitated. This has particular advantages when it is desired to tow the structure to a wind farm, and also has an important advantage as will be described below for facilitating urging of the semi-submersible structure downwardly in the water by the primary ligature.

The provision of the ballast receiving means, and in particular, the provision of

ballast chambers facilitates ballasting of the semi-submersible structure with ballasting material, for example, sand pumped from the sea bed into the respective ballast chambers after the semi-submersible structure has been towed to the wind farm. Indeed, it is envisaged that in certain cases where it is desired to increase the buoyancy of the semi-submersible structure, for example, after it has been urged downwardly in the water by the primary ligature, the ballast material in the ballast chambers may be pumped out or otherwise removed.

The invention will be more clearly understood from the following description of some preferred embodiments thereof, which are given by way of example only, with reference to the accompanying drawings, in which:

Fig. 1 is a partly cross-sectional side elevational view of a wind powered generator according to the invention comprising a floatable structure also according to the invention,

Fig. 2 is an enlarged partly cross-sectional side elevational view of the wind powered generator of Fig. 1,

Fig. 3 is a cross-sectional side elevational view of a portion of the floatable structure of Fig. 1,

Fig. 4 is a cross-sectional side elevational view of another portion of the floatable structure of Fig. 1,

Fig. 5 is a side elevational view of a plurality of wind powered generators illustrated located in a wind farm,

Fig. 6 is a plan view of the wind powered generators of Fig. 5,

Fig. 7 is a schematic diagram of the semi-submersible structure, in use,

Fig. 8 is a partly cross-sectional side elevational view of a wind powered generator according to another embodiment of the invention,

Fig. 9 is an underneath plan view of the wind powered generator of Fig. 8, and

Fig. 10 is a transverse cross-sectional view of a detail of the wind powered generator of Fig. 8.

Referring to the drawings and initially to Figs. 1 to 4, there is illustrated a wind energy converter according to the invention for converting wind energy to usable power, which in this embodiment of the invention is a wind powered generator indicated generally by the reference numeral 1 for converting wind energy to electrical power. The wind powered generator 1 comprises a floatable structure also according to the invention indicated generally by the reference numeral 2 for locating a wind turbine 3 offshore in relatively deep water. The floatable structure 2 comprises a semi-submersible structure 5, and a mast 6 extends upwardly from the semi-submersible structure 5 for carrying the wind turbine 3. In this embodiment of the invention the wind turbine 3 is a horizontal axis wind turbine, and is of a type which will be well known to those skilled in the art.

The semi-submersible structure 5 comprises a main housing 9 formed by an outer shell 10 which defines a hollow interior region 11 which is subdivided into a plurality of chambers as will be described below. The outer shell 3 is of substantially bell shape and defines a vertically extending main geometric central axis 12 of the semi-submersible structure 5, when viewed in plan is of circular cross-section. A transversely extending top wall 14 extends across the hollow interior region 11 and is sealably secured to the outer shell 10 and defines with a portion of the outer shell 10 and a side wall 5 a primary buoyancy chamber 16. The side wall 15 is of inverted frusto-conical shape and extends downwardly inwardly from the outer shell 10 to which it is sealably secured for forming the primary buoyancy chamber 16. An annular base 17 extending inwardly from the outer shell 10 at the bottom thereof to the side wall 15 defines with the outer shell 10 and the side wall 15 a ballast

receiving means, namely, a ballast chamber 19 which extends around the primary buoyancy chamber 16 for receiving ballast material for ballasting the semi-submersible structure 5. A plurality of equi-spaced apart radially extending panels 21 extend between the side wall 15, portion of the outer shell 10 and the base 17 for dividing the ballast chamber 19 into a plurality of ballast chamber compartments.

The base 17 defines a communicating opening 20 to the primary buoyancy chamber 16 for admitting water into the primary buoyancy chamber 16 for compressing air therein to a pressure of the adjacent water when the semi-submersible structure 5 is semi-submerged as will be described below. The communicating opening 20 also accommodates water being displaced from the primary buoyancy chamber 16 by compressed air which is pumped into the primary buoyancy chamber 16 as will be described below for increasing the buoyancy of the semi-submersible structure 5.

A primary connecting means comprising a primary connecting bracket 22 is mounted on the top wall 14 in the top dead centre of the primary buoyancy chamber 16 on the main central axis 12 for connecting a primary ligature, namely, a primary anchor cable 23 to the semi-submersible structure 5. The primary anchor cable 23 extends vertically downwardly from the primary connecting bracket 22 through the primary buoyancy chamber 16 and in turn through the communicating opening 20 to a primary anchorage 24 on the sea bed 25, see Fig. 5. The diameter of the communicating opening 20 and that of the primary anchor cable 23 is such as to accommodate water through the communicating opening 20.

A winching mechanism (not shown) is provided in conjunction with the primary anchor cable 23 for winching the semi-submersible structure 5 downwardly in the water by the primary anchor cable 23 against the upwardly directed buoyancy force which acts on the semi-submersible structure 5. By so winching the semi-submersible structure downwardly in the water the centre of flotation 26, see Fig. 7, of the semi-submersible structure 5 is raised, for in turn increasing the righting moment on the semi-submersible structure 5 for returning the semi-submersible structure 5 to its equilibrium flotation state in the event that the semi-submersible

structure 5 has tilted through an angle α from the vertical from its equilibrium flotation state. The centre of flotation 26 and the centre of gravity 27 of the semi-submersible structure 5 lie on the main central axis 12. In this embodiment of the invention the semi-submersible structure 5 is appropriately ballasted so that the centre of gravity 27 of the combination of the semi-submersible structure 5, the wind turbine 3 and the mast 6 are located below the primary connecting bracket 22, and when the semi-submersible structure 5 is urged downwardly in the water by the primary anchor cable 23 the centre of flotation of the semi-submersible structure 5 is located above the primary connecting bracket 22, see Fig. 7. This, thus, causes the resultant turning moment of the turning moment acting through the centre of gravity 27 in the direction of the arrow A and the turning moment acting through the centre of flotation 26 in the direction of the arrow B to be a righting turning moment acting through the centre of flotation 26, for urging the semi-submersible structure into its equilibrium flotation state in the event that the structure has tilted through the angle α from the vertical from its equilibrium flotation state. In this embodiment of the invention the semi-submersible structure is urged downwardly in the water sufficiently so that the resultant righting moment acting on the semi-submersible structure 5 through the centre of flotation is sufficient to return the semi-submersible structure 5 to its equilibrium flotation state once the semi-submersible structure 5 has tilted with its main central axis inclined to the vertical at the angle α of not more than 6°. In other words, the resultant righting moment acting on the semi-submersible structure is such as to maintain the semi-submersible structure with its main central axis 12 within a cone angle 2α around the vertical not exceeding 12°. Although preferably, the semi-submersible structure 5 is urged downwardly in the water sufficiently so that the resulting righting moment maintains the semi-submersible structure 5 with its main central axis 12 within a cone angle 2α not exceeding 5°.

It will of course be appreciated that the further the semi-submersible structure 5 tilts from its equilibrium flotation state about the vertical, in other words the greater the angle α the greater will be the righting moment acting through the centre of flotation, thereby ensuring rapid return of the semi-submersible structure to its equilibrium flotation state.

Additionally, the communicating opening 20 is of sufficiently small diameter so that when the semi-submersible structure 5 has tilted through a relatively small angle, typically, not more than 6° from the vertical, the base 17 engages the primary anchor cable 23 which thereby causes the semi-submersible structure 5 to tend to pivot about the primary anchor cable 23 adjacent the communicating opening 20 which further assists in increasing the resultant righting moment for returning the semi-submersible structure to its equilibrium flotation state.

Reinforcing struts 31 extend between the outer shell 10 and the primary connecting bracket 22 for supporting and reinforcing the primary connecting bracket 22.

A plurality of auxiliary connecting means, namely, six auxiliary connecting brackets 28 are located at equi-spaced apart intervals circumferentially around the outer periphery of the outer shell 10 at the lower end thereof, for connecting corresponding auxiliary ligatures, namely, auxiliary anchoring cables 29 to the semi-submersible structure 5 for further stabilising and anchoring the semi-submersible structure 5. The auxiliary anchor cables 29 extend from the corresponding auxiliary connecting brackets 28 in a general downwardly, radially outward direction to auxiliary anchorages 30 located in the sea bed 25. The auxiliary anchorages 30 are spaced apart a considerable radial distance from the main central axis 12 so that the auxiliary anchor cables 29 extend from the auxiliary connecting brackets 28 downwardly at an angle of approximately 70° to the vertical, and then extend in a cathenary to the corresponding auxiliary anchorage 30.

A secondary buoyancy chamber 34 is formed by the outer shell 10 and a transversely extending wall 35 which sealably engages the outer shell 10. The secondary buoyancy chamber 34 extends upwardly from the wall 35 to a transversely extending top wall 36 which closes the secondary buoyancy chamber 34 above the waterline of the semi-submersible structure 2 when the semi-submersible structure 2 has been urged downwardly in the water by the primary anchor cable 23. In certain cases since the wall 36 is above the waterline of the

semi-submersible structure 5, the wall 36 may be omitted. Typically, the secondary buoyancy chamber 34 contains air. The provision of the secondary buoyancy chamber 34 tends to further rise the centre of buoyancy of the semi-submersible structure 5, and in turn its centre of flotation 26.

The wall 35 defines with the top wall 14 and a portion of the outer shell 10 a component chamber 37 for accommodating an electrical generator 39, which is illustrated in block representation only for generating electricity. A transmission means, namely, a drive transmission shaft 40 extends downwardly through the mast 6 from the wind turbine 3 to the electrical generator 39 for driving the generator 39. The component chamber 37 also acts as a buoyancy chamber. A control panel (not shown) and other control equipment (also not shown) for controlling the electrical generator 39 is also located in the component chamber 37.

A communicating port 41 through the top wall 14 permits compressed air to be pumped into the primary buoyancy chamber 16 for increasing the buoyancy of the semi-submersible structure 5 after the semi-submersible structure 5 has been urged downwardly in the water by the primary anchor cable 23. A compressor (not shown) is located in the component chamber 37 for compressing the air to be delivered into the primary buoyancy chamber 16 through the communicating port 41. Suitable valving is provided in the communicating port 41 for facilitating sealing of the primary buoyancy chamber 16, and also for facilitating exhausting air from the primary buoyancy chamber 16 should it be desired to reduce the buoyancy of the semi-submersible structure 5.

The ballast receiving means also comprises a plurality of ballast engaging means, namely, ballast mounting brackets 42 for releasably mounting ballast members 43 to the base 17 of the semi-submersible structure 5 for increasing ballast of the semi-submersible structure 5. The ballast members 43 are solid slabs of suitable ballasting material, for example, lead, concrete, cast iron or the like.

A main mounting means comprising a mounting flange 45 extends around the semi-

submersible structure 5 at the top of the main housing 9 for receiving and abutting a corresponding mounting flange 46 of the mast 6. Screws or other suitable fasteners are provided for securing the respective mounting flanges 45 and 46 together.

The semi-submersible structure 5 according to this embodiment of the invention may be of any suitable or desirable material, for example, it may be of concrete, steel, plastics material, fibreglass material, or indeed any other suitable or desirable material. It is, however, envisaged that it may be formed of cast iron sections which would be sealably secured together in order to form the outer shell 10 and the respective walls 14, 15, 35 and 36, as well as the base 17.

The outer shell 10 tapers upwardly so that the transverse cross-section of the main housing 9 adjacent the waterline of the semi-submersible structure 5 when the semi-submersible structure 5 has been urged downwardly by the primary anchor cable 23 is relatively narrow for minimising resistance to passing waves.

Referring now to Figs. 5 and 6, there is illustrated a portion of a wind farm also according to the invention indicated generally by the reference numeral 50. The wind farm 50 comprises a plurality of the wind powered generators 1 according to the invention which are arranged in a plurality of parallel equi-spaced apart rows 51. The wind powered generators 1 of alternate rows 51 are staggered relative to those of their respective adjacent rows 51, and as can be seen, the wind powered generators 1 of alternate rows 51 are located substantially halfway between the wind powered generators 1 of their respective adjacent rows 51. The primary anchorage 24 of each semi-submersible structure 5 acts as the auxiliary anchorage 30 for respective wind powered generators 1 which are spaced apart by one wind powered generator 1 from the wind powered generator of which the primary anchorage 24 is acting as the auxiliary anchorage 30. The wind farm 50 may comprise any number of wind powered generators 1, however, typically, it is envisaged that a wind farm would contain up to two hundred and fifty wind powered generators 1 which would typically be arranged in fifty rows 51, where each row 51 contains fifty wind powered generators 1.

Stabilising cables 52 extend from the auxiliary anchor cables 29 to the primary anchorage 24 for stabilising the auxiliary anchor cables 29.

In order to set up a wind farm 50 of the type illustrated in Figs. 5 and 6, the sea bed is initially prepared and primary anchorages 24 are located at appropriately spaced apart positions for anchoring the wind powered generators 1. Auxiliary anchorages 30 are also provided for the wind powered generators 1 on the periphery of the wind farm 50 and also for those wind powered generators 1 one in from the periphery. The anchorages 24 and 30 may be any suitable anchorages, and typically, will be formed by drilling into the sea bed 25, and filling the holes drilled into the sea bed with cast concrete, epoxy resin, or other suitable materials. Suitable anchorage brackets would be cast into the concrete or other cast material for connecting to the primary and auxiliary anchor cables 23 and 29. However, in certain cases it is envisaged that the primary and auxiliary anchor cables 23 and 29 may be cast directly into the drilled holes by a suitable castable material, for example, concrete and in certain cases, epoxy resin.

After the primary and auxiliary anchorages 24 and 30 have been located and secured in the sea bed 25 the floatable structures 2 with the masts 6 and wind turbines 3 assembled thereto are floated by towing out to the location of the wind farm 50. During towing of the wind powered generators 1 to the location of the wind farm 50 typically, the primary buoyancy chambers 6 of the respective semi-submersible structures 5 are partially filled with air, and if necessary, ballast may be added to the semi-submersible structures 5 by either pumping ballast, for example, sea sand, into the ballast chambers 19 or securing ballast members 43 to the semi-submersible structure 5. However, during towing of the wind powered generators 1 to the location of the wind farm 50, the buoyancy and ballasting of the semi-submersible structure 5 is such that the centre of flotation of the semi-submersible structure 1 and its centre of gravity lie on the main central axis 12 and the centre of flotation is located above the centre of gravity.

When towed to the location of the wind farm 50, the wind powered generators 1 are aligned with their respective corresponding primary anchorages 24. The primary anchor cables 23 are connected to the primary connecting brackets 22, and lowered downwardly to the primary anchorages 24 and secured thereto. In order to reduce the buoyancy of the semi-submersible structures 5 to facilitate winching of the semi-submersible structures 5 downwardly in the water, the primary buoyancy chambers 16 are evacuated of air through the communicating ports 41, thus admitting water into the primary buoyancy chambers 16 through the communicating openings 20. Added ballast may be added to the semi-submersible structures 5 by, for example, pumping sand into the ballast compartments of the ballast chambers 19, and/or attaching further ballast members 23 to the ballast mounting brackets 42. The winch mechanisms (not shown) of the respective primary anchor cables 23 of the respective semi-submersible structures 5 are then operated for urging the semi-submersible structures 5 downwardly in the water for in turn raising the centre of flotation of the semi-submersible structures 5 and in turn of the wind powered generators 1. After the semi-submersible structures 5 have been urged sufficiently downwardly in the water, compressed air is pumped into the primary buoyancy chamber 16 of each of the semi-submersible structures 5 for displacing water through the communicating opening 20 for increasing the buoyancy of the structures 5. Some of the ballast, for example, the sand which had been pumped into the compartments of the ballast chamber 19, may be removed, or some or all of the ballast members 43 may be removed for further increasing the buoyancy of each of the wind powered generator 1, and thus further raising its centre of flotation 26. The auxiliary anchor cables 29 are next attached to the auxiliary connecting brackets 28 and in turn to the auxiliary anchorages 30 for further anchoring the respective semi-submersible structures 5.

At this stage the wind powered generators 1 are ready for use, and electrical cables from the electrical generators 39 are run along the sea bed to a land based control station for connection into an onshore mains electricity supply network, or for otherwise distributing the electrical power.

In use, each semi-submersible structure 5 is anchored and stabilised by the primary anchor cable 23 and the auxiliary anchor cables 29. By virtue of the fact that the primary anchor cable 23 extends downwardly from the wind powered generator 1 and urges the semi-submersible structure 5 downwardly against the normal upward buoyancy force acting on the semi-submersible structure 5, the centre of flotation 26 of the semi-submersible structure 5, and in turn the centre of flotation 26 of the combined semi-submersible structure 5, the wind turbine 3 and the mast 6 is significantly raised, thereby increasing the resultant righting moment acting on the semi-submersible structure 5 should the semi-submersible structure 5 tilt with its main central axis 12 tilted from the vertical. Indeed, as already discussed, the semi-submersible structure 5 of each wind powered generator 1 is urged sufficiently downwardly in the water so that the resultant righting moment acting on the semi-submersible structure 5 maintains the semi-submersible structure 5 with its main central axis 12 within a cone angle of 2α which does not exceed 12°, and preferably does not exceed 5°.

Indeed, the further the semi-submersible structure 5 is urged downwardly in the water, the higher the centre of flotation is urged, and its distance from the centre of gravity is likewise increased. This, thus, further increases the righting moment acting on the semi-submersible structure 5 for returning the semi-submersible structure 5 to its equilibrium flotation state in the event of it tilting therefrom from the vertical.

Additionally, as well as the righting moment acting through the centre of flotation for returning the semi-submersible structure 5 to its equilibrium flotation state, the provision of the auxiliary anchor cables further provide a righting moment for righting the semi-submersible structure 5.

In practice it is envisaged that the mast 6 will be of length in the range of 50 metres to 100 metres. The height of the semi-submersible structure 5 from the base 17 to the mounting flange 45 will be in the range of 50 metres to 100 metres. The outer diameter of the semi-submersible structure 5 adjacent the mounting flange 45 will typically be in the range of 4 metres to 5 metres, and the outer diameter of the semi-

submersible structure 5 adjacent the base 5 will be in the range of 25 metres to 35 metres. Ideally, the outer diameter of the main housing 9 adjacent the waterline will be in the range of 5 metres to 6 metres.

It is envisaged that typically, the volume of the primary buoyancy chamber 16 will be in the order of 3,500 cubicmetres, while the volume of the secondary buoyancy chamber 34 will be in the order of 100 cubicmetres. The total volume of the ballast chamber 19 will be in the order of 13,500 cubicmetres, which may be partially or completely filled with ballast, such as, for example, sea sand or alternatively some or all of the compartments of the ballast chamber 19 may be flooded.

The weight of ballast and the buoyancy of the semi-submersible structure 5 will depend on the amount of tension to be induced in the primary anchor cable 23. The effective length of the primary anchor cable 23 of each semi-submersible structure 5 will depend on the depth of water and the amount by which the semi-submersible structure 5 is to be urged downwardly in the water. The length of the auxiliary anchor cables 29 will also be a function of the depth of water, however, in general, it is envisaged that the auxiliary anchor cables 29 and the auxiliary anchorages 30 will be located so that the auxiliary anchor cables 29 will extend from the auxiliary connecting brackets 28 at an angle of approximately 50° to 75° to the vertical and will then proceed in the form of a cathenary to the auxiliary anchorages 30.

Referring now to Figs. 8 to 10, there is illustrated a wind powered generator according to another embodiment of the invention indicated generally by the reference numeral 60. The wind powered generator 60 is substantially similar to the wind powered generator 1 and similar components are identified by the same reference numerals. Additionally, the wind powered generator 60 is also suitable for locating in the wind farm 50. The main difference between the wind powered generator 60 and the wind powered generator 1 is in the construction of the main housing 9, and in addition to the primary and auxiliary anchor cables 23 and 29, respectively, secondary ligatures, namely, secondary anchor cables 62 are also provided for further anchoring and stabilising the semi-submersible structure 5, and

for damping oscillating movement of the semi-submersible structure 5 about the vertical axis.

In this embodiment of the invention an outwardly extending base flange 63 extends outwardly from the base 17 of the semi-submersible structure 5 for facilitating connecting of the secondary anchor cables 62 to the semi-submersible structure 5. Twelve secondary anchor cables 62 are provided, and twelve corresponding secondary connecting means, namely, twelve secondary connecting brackets 65 are located on the base flange 63 at equi-spaced apart intervals circumferentially around the outer periphery of the semi-submersible structure 5. Each secondary connecting bracket 65 is resiliently mounted to the base flange 63 by a compression spring 66 for facilitating resilient mounting of the corresponding secondary anchor cable 62 to the semi-submersible structure 5 for damping oscillating movement of the semi-submersible structure 5 about the vertical, see Fig. 10. Bores 68 through the base flange 63 accommodate the secondary anchor cables 62 to the secondary connecting brackets 65. Accordingly, as the base flange 63 adjacent a secondary connecting bracket 65 commences to move upwardly as the semi-submersible structure 5 tilts from the vertical, the corresponding compression spring 66 is compressed for damping the upward movement, and in turn for damping the tilting movement of the semi-submersible structure 5.

The secondary anchor cables 62 extend vertically downwardly from the secondary connecting brackets 65 to corresponding secondary anchorages 69 in the sea bed 25. Winching mechanisms (not shown) are provided in conjunction with the secondary anchor cable 62 for facilitating tightening of the secondary anchor cable 62 after the primary anchor cable 23 has been winched for urging the semi-submersible structure 5 downwardly in the water so that the compression springs 66 are just barely compressed when the semi-submersible structure 5 is in its equilibrium flotation state.

In addition to the primary and secondary buoyancy chambers 16 and 34, respectively, auxiliary buoyancy chambers 70 are provided around the primary and

secondary buoyancy chambers 16 and 34 for further increasing the buoyancy of the semi-submersible structure 5.

Additionally, in this embodiment of the invention the communicating opening 20 is of considerably larger diameter than that of the semi-submersible structure 5 of the wind powered generator 1, and in this embodiment of the invention the base 17 does not bear on the primary anchor cable 23 during normal tilting of the semi-submersible structure 5 about the vertical.

The wind powered generator 60 according to this embodiment of the invention is particularly suitable for use in relatively shallow waters. The provision of the secondary anchor cables 65 are particularly suitable for minimising tilting of the semi-submersible structure 5 where the amount by which the semi-submersible structure 5 can be urged downwardly in the water by the primary anchor cable is limited by virtue of the water depth.

Otherwise the wind powered generator 60 according to this embodiment of the invention is similar to the wind powered generator 1, as is its operation.

Typically, the outer diameter of the main housing 9 of the wind powered generator 60 adjacent the waterline is approximately 6 metres. The outer diameter of the main housing 9 adjacent the base 17 is approximately 30 metres. The overall height of the semi-submersible structure 5 from the base 17 to the mounting flange 45 is typically 20 metres, while the height of the mast 6 is of the order of 80 metres. In this embodiment of the invention it is envisaged that the mast 6 will be of length in the range of 50 metres to 100 metres. The height of the semi-submersible structure 5 from the base 17 to the mounting flange 45 will be in the range of 50 metres to 100 metres. The outer diameter of the semi-submersible structure 5 adjacent the mounting flange 45 will typically be in the range of 4 metres to 5 metres, and the outer diameter of the semi-submersible structure 5 adjacent the base 5 will be in the range of 25 metres to 35 metres. Ideally, the outer diameter of the main housing 9 adjacent the waterline will be in the range of 5 metres to 6 metres.

It is envisaged that typically, the volume of the primary buoyancy chamber 16 will be in the order of 3,500 cubicmetres, while the volume of the secondary buoyancy chamber 34 will be in the order of 100 cubicmetres. The total volume of the ballast chamber 19 will be in the order of 13,500 cubicmetres, which may be partially or completely filled with ballast, such as, for example, sea sand or alternatively some or all of the compartments of the ballast chamber 19 may be flooded.

It is envisaged that an air separation plant for separating carbon from air may be located in the component chamber or elsewhere, and would be driven by the turbine. Needless to say, it will be appreciated that the compressor may be driven directly by the turbine or may be electrically powered by the electrical generator.

While the semi-submersible structure of the wind powered generator 1 has been described as having a relatively small communicating opening into the primary buoyancy chamber, it is envisaged that the opening into the primary buoyancy chamber of the wind powered generator 1 may be of relatively large diameter, and it is envisaged that the primary buoyancy chamber of the semi-submersible structure of the wind powered generator 1 may be of similar shape and construction to that of the wind powered generator 60.

It is also envisaged that in certain cases the semi-submersible structure of the wind powered generator 1 may be provided with secondary anchor cables substantially similar to those described with reference to the wind powered generator 60.

While the wind powered generators have been described as comprising horizontal axis turbines, the turbines may be vertical axis turbines. It is also envisaged that instead of generating electricity, the wind energy converters according to the invention may be adapted for converting wind energy to any other suitable usable form of energy.

Claims

1. A method for locating a wind turbine (3) offshore characterised in that the method comprises the steps of locating the wind turbine (3) on a mast (6) extending upwardly from a floatable semi-submersible structure (5), anchoring the semi-submersible structure (5) by a primary ligature (23) extending in a generally downwardly direction from the semi-submersible structure (5), and urging the semi-submersible structure (5) downwardly in the water by the primary ligature (23) below its normal flotation level against an upwardly directed buoyancy force acting on the semi-submersible structure (5) for raising the centre of flotation (26) of the semi-submersible structure (5) for in turn increasing the righting moment acting on the semi-submersible structure (5) for returning the semi-submersible structure (5) to its equilibrium flotation state.

2. A method as claimed in Claim 1 characterised in that the semi-submersible structure (5) is anchored by the primary ligature (23) to a primary anchorage (24) in the sea bed (25).

3. A method as claimed in Claim 1 or 2 characterised in that the semi-submersible structure (5) defines a main central geometric axis (12), which extends vertically when the semi-submersible structure (5) is in its equilibrium flotation state, and the primary ligature (23) is connected to the semi-submersible structure (5) on the main central axis (12).

4. A method as claimed in Claim 3 characterised in that the primary ligature (23) coincides with the main central axis (12) of the semi-submersible structure (5).

5. A method as claimed in any preceding claim characterised in that the semi-submersible structure (5) is urged downwardly by the primary ligature (23) so that the centre of flotation (26) is above the centre of gravity (27) of the semi-submersible structure (5).

6. A method as claimed in any preceding claim characterised in that the semi-

submersible structure (5) is urged downwardly by the primary ligature (23) so that the centre of flotation (26) is above the centre of gravity (27) of the combined semi-submersible structure (5), the mast (6) and the wind turbine (3).

7. A method as claimed in any preceding claim characterised in that the semi-submersible structure (5) is urged downwardly by the primary ligature (23) so that the relative position of the centre of flotation (26) and the centre of gravity (27) is such as to provide a sufficient righting moment acting through the centre of flotation (26) for returning the semi-submersible structure (5) to its equilibrium flotation state.

8. A method as claimed in Claim 7 characterised in that the semi-submersible structure (5) is urged downwardly by the primary ligature (23) so that the righting moment acting through the centre of flotation (26) for returning the semi-submersible structure (5) to its equilibrium flotation state is sufficient for returning the semi-submersible structure (5) to its equilibrium state on the semi-submersible structure (5) tilting to an extent that the main central axis (12) of the semi-submersible structure falls outside a vertically extending cone angle not greater than 12°.

9. A method as claimed in Claim 8 characterised in that the cone angle does not exceed 8°.

10. A method as claimed in Claim 8 characterised in that the cone angle does not exceed 5°.

11. A method as claimed in any preceding claim characterised in that the semi-submersible structure (5) is urged downwardly by the primary ligature (23) so that the point of connection (22) at which the primary ligature (23) is connected to the semi-submersible structure (5) lies between the centre of flotation (26) and the centre of gravity (27) of the semi-submersible structure (5).

12. A method as claimed in any preceding claim characterised in that the semi-submersible structure (5) is further anchored by a plurality of secondary ligatures

(62) extending in a generally downwardly direction from the semi-submersible structure (5) for limiting movement of the semi-submersible structure (5) from its equilibrium flotation state, the secondary ligatures (62) being spaced apart circumferentially around and radially from the main central axis (12).

13. A method as claimed in Claim 12 characterised in that the secondary ligatures (62) are equi-spaced apart circumferentially around the main central axis (12).

14. A method as claimed in Claim 12 or 13 characterised in that each secondary ligature (62) is anchored to the sea bed (25) by a corresponding secondary anchorage (69).

15. A method as claimed in any of Claims 12 to 14 characterised in that each secondary ligature (62) is resiliently connected to one of the semi-submersible structure (5) and the sea bed (25) for damping movement of the semi-submersible structure (5) from its equilibrium flotation state.

16. A method as claimed in Claim 15 characterised in that each secondary ligature (62) is resiliently connected to the semi-submersible structure (5).

17. A method as claimed in any of Claims 12 to 16 characterised in that at least three secondary ligatures (62) are provided.

18. A method as claimed in any of Claims 12 to 17 characterised in that at least four secondary ligatures (62) are provided.

19. A method as claimed in any of Claims 12 to 18 characterised in that the secondary ligatures (62) are connected to the semi-submersible structure (5) at connection points on a common pitch circle.

20. A method as claimed in any of Claims 12 to 19 characterised in that the

secondary ligatures (62) are connected to the semi-submersible structure (5) adjacent a periphery thereof.

21. A method as claimed in any of Claims 12 to 20 characterised in that the secondary ligatures (23) are connected to the semi-submersible structure (5) adjacent an outer periphery thereof.

22. A method as claimed in any preceding claim characterised in that the semi-submersible structure (5) is further anchored by a plurality of auxiliary ligatures (29) connected to the semi-submersible structure (5) at locations (28) spaced apart circumferentially around the main central axis (12), the respective auxiliary ligatures (29) extending in a generally downwardly, radially outwardly direction of the semi-submersible structure (5).

23. A method as claimed in Claim 22 characterised in that the respective auxiliary ligatures (29) are connected to the semi-submersible structure (5) at equi-spaced apart auxiliary locations circumferentially around the main central axis (12).

24. A method as claimed in Claim 22 or 23 characterised in that each auxiliary ligature (29) extends downwardly, radially outwardly from the semi-submersible structure (5) at an angle to the vertical in the range of 1° to 89° and continues in a cathenary towards a corresponding radially outwardly spaced apart auxiliary anchorage (30) in the sea bed (25) spaced apart radially outwardly from the primary anchorage (24).

25. A method as claimed in Claim 24 characterised in that each auxiliary ligature (29) extends downwardly, radially outwardly from the semi-submersible structure (5) at an angle to the vertical in the range of 60° to 80°.

26. A method as claimed in Claim 25 characterised in that each auxiliary ligature (29) extends downwardly, radially outwardly from the semi-submersible structure (5) at an angle to the vertical of approximately 70°.

27. A method as claimed in any of Claims 22 to 26 characterised in that the auxiliary ligatures (29) are connected to the semi-submersible structure at connection points (28) on a common pitch circle.

28. A method as claimed in any of Claims 22 to 27 characterised in that the auxiliary ligatures (29) are connected to the semi-submersible structure (5) adjacent a periphery thereof.

29. A method as claimed in any of Claims 22 to 29 characterised in that the auxiliary ligatures (29) are connected to the semi-submersible structure (5) adjacent an outer periphery thereof.

30. A method as claimed in any preceding claim characterised in that a primary buoyancy chamber (16) is located in the semi-submersible structure (5), the primary buoyancy chamber (16) defining a central geometric axis coinciding with the main central axis (12) of the semi-submersible structure (5).

31. A method as claimed in Claim 30 characterised in that the primary ligature (23) extends into the primary buoyancy chamber (16) and is connected to the semi-submersible structure (5) within the primary buoyancy chamber (16).

32. A method as claimed in Claim 30 or 31 characterised in that a communicating opening (20) is provided in the bottom of the semi-submersible structure (5) to the primary buoyancy chamber (16) for accommodating the primary ligature (23) into the primary buoyancy chamber (16).

33. A method as claimed in any of Claims 30 to 32 characterised in that the primary ligature (23) is connected to the semi-submersible structure (5) in the primary buoyancy chamber (16) at the top dead centre (22) of the primary buoyancy chamber (16).

34. A method as claimed in any of Claims 30 to 33 characterised in that compressed air is pumped into the primary buoyancy chamber (16) for expelling water therefrom through the communicating opening (20) for increasing the buoyancy of the semi-submersible structure (5).

35. A method as claimed in any preceding claim characterised in that ballast is applied to the semi-submersible structure for ballasting the semi-submersible structure (5).

36. A method as claimed in Claim 35 characterised in that the ballast is applied to the lower end of the semi-submersible structure (5).

37. A method as claimed in Claim 35 or 36 characterised in that the ballast is applied circumferentially around the main central axis (12).

38. A method as claimed in any of Claims 35 to 37 characterised in that the ballast is radially spaced apart from the main central axis (12).

39. A method as claimed in any preceding claim characterised in that the mast (6) defines a geometric central axis, and is mounted on the semi-submersible structure (5) with its central axis coinciding with the central axis of the semi-submersible structure (5).

40. A method as claimed in any preceding claim characterised in that the turbine (3) is mounted on top of the mast (5).

41. A method as claimed in any preceding claim characterised in that the turbine (3) is a horizontal axis turbine.

42. A method as claimed in any of Claims 1 to 41 characterised in that the turbine (3) is a vertical axis turbine.

43. A method as claimed in any preceding claim characterised in that the turbine (3) drives an electrical generator (39) for generating electricity.

44. A method as claimed in Claim 43 characterised in that the electrical generator (39) is located adjacent the turbine (3).

45. A method as claimed in Claim 43 characterised in that the electrical generator (39) is located in the semi-submersible structure (5), and a drive transmission means (40) is provided between the turbine (3) and the electrical generator (39).

46. A floatable structure (2) for carrying and locating a wind turbine (3) offshore, the floatable structure (2) comprising a semi-submersible structure (5) having a primary buoyancy chamber (16), and comprising a mounting means (22) located thereon for mounting a mast (6) extending upwardly therefrom for carrying the wind turbine (3) thereon, and a primary connecting means (22) for connecting a primary ligature (23) to the semi-submersible structure (5) with the primary ligature (23) extending in a generally downwardly direction therefrom for anchoring the semi-submersible structure (5) and for urging the semi-submersible structure (5) downwardly in the water against an upwardly directed buoyancy force acting thereon for raising the centre of flotation (26) of the semi-submersible structure (5) for in turn increasing the righting moment acting on the semi-submersible structure (5) for returning the semi-submersible structure to its equilibrium flotation state.

47. A floatable structure as claimed in Claim 46 characterised in that the semi-submersible structure (5) defines a main central geometric axis (12) which extends vertically when the semi-submersible structure (5) is in its equilibrium flotation state, and the primary connecting means (22) is located on the main central axis (12) of the semi-submersible structure (5).

48. A floatable structure as claimed in Claim 46 or 47 characterised in that the primary connecting means (22) connects the primary ligature (23) to the semi-

submersible structure (5) to extend in a generally downwardly direction to a primary anchorage (24) in the sea bed (25).

49. A floatable structure as claimed in any of Claims 46 to 48 characterised in that the centre of gravity (27) of the semi-submersible structure (5) is located so that when the semi-submersible structure (5) is urged downwardly by the primary ligature (23) the centre of flotation (26) is above the centre of gravity (27).

50. A floatable structure as claimed in any of Claims 46 to 49 characterised in that the centre of gravity (27) of the semi-submersible structure (5) is below the centre of flotation of the semi-submersible structure (5) when the semi-submersible structure (5) is freely floating.

51. A floatable structure as claimed in any of Claims 46 to 50 characterised in that the centre of gravity (27) and the centre of flotation (26) of the semi-submersible structure (5) lie on the main central axis (12) of the semi-submersible structure.

52. A floatable structure as claimed in any of Claims 46 to 51 characterised in that the primary connecting means (22) is located intermediate the centre of gravity (27) and the centre of flotation (26) of the semi-submersible structure when the semi-submersible structure (5) is urged downwardly in the water by the primary ligature (23).

53. A floatable structure as claimed in any of Claims 46 to 52 characterised in that the centre of flotation (26) is above the centre of gravity (27) by an amount sufficient to provide a righting moment acting through the centre of flotation (26) for returning the semi-submersible structure (5) to its equilibrium flotation state.

54. A floatable structure as claimed in Claim 53 characterised in that the centre of flotation (26) is above the centre of gravity (27) of the semi-submersible structure (5) by an amount so that the righting moment acting through the centre of flotation (26) is sufficient for returning the semi-submersible structure (5) to its equilibrium

flotation state when the semi-submersible structure (5) has tilted from its equilibrium flotation state with its main central axis (12) lying outside a vertical cone angle not exceeding 12°.

55. A floatable structure as claimed in Claim 54 characterised in that the centre of flotation (26) is above the centre of gravity (27) of the semi-submersible structure (5) by an amount so that the righting moment acting through the centre of flotation (26) is sufficient for returning the semi-submersible structure (5) to its equilibrium flotation state when the semi-submersible structure (5) has tilted from its equilibrium flotation state with its main central axis (12) lying outside a vertical cone angle not exceeding 8°.

56. A floatable structure as claimed in Claim 55 characterised in that the centre of flotation (26) is above the centre of gravity (27) of the semi-submersible structure (5) by an amount so that the righting moment acting through the centre of flotation (26) is sufficient for returning the semi-submersible structure (5) to its equilibrium flotation state when the semi-submersible structure (5) has tilted from its equilibrium flotation state with its main central axis (12) lying outside a vertical cone angle not exceeding 5°.

57. A floatable structure as claimed in any of Claims 46 to 56 characterised in that a communicating opening (20) in the lower end of the semi-submersible structure (5) is provided to the primary buoyancy chamber (16) for accommodating the primary ligature (23) into the primary buoyancy chamber (16).

58. A floatable structure as claimed in Claim 57 characterised in that the primary connecting means (22) is located in the primary buoyancy chamber (16).

59. A floatable structure as claimed in Claim 57 or 58 characterised in that the primary connecting means (22) is located at the top dead centre of the primary buoyancy chamber (16).

60. A floatable structure as claimed in any of Claims 57 to 59 characterised in that the communicating opening (20) is adapted for accommodating water therethrough into and out of the primary buoyancy chamber (16) for altering the buoyancy of the semi-submersible structure (5).

61. A floatable structure as claimed in any of Claims 57 to 60 characterised in that the diameter of the communicating opening (20) to the primary buoyancy chamber (16) is such that the semi-submersible structure (5) engages the primary ligature (23) at the communicating opening (20) when the semi-submersible structure (5) tilts for causing the semi-submersible structure (5) to tilt about the primary ligature (23) adjacent the communicating opening (20).

62. A floatable structure as claimed in any of Claims 57 to 61 characterised in that the diameter of the communicating opening (20) is slightly greater than the diameter of the primary ligature (23) for accommodating water into and out of the primary buoyancy chamber (16) past the primary ligature (20).

63. A floatable structure as claimed in any of Claims 46 to 62 characterised in that a communicating port (41) is provided to the primary buoyancy chamber (16) for facilitating delivery of a buoyancy medium to and exhausting the buoyancy medium from the primary buoyancy chamber (16) for altering the buoyancy of the semi-submersible structure (5).

64. A floatable structure as claimed in Claim 63 characterised in that the communicating port (20) is adapted for accommodating air into and from the primary buoyancy chamber (16).

65. A floatable structure as claimed in any of Claims 46 to 64 characterised in that a ballast receiving means (19, 42) is provided in the semi-submersible structure (5) for receiving ballast for ballasting the semi-submersible structure (5) and for altering the buoyancy of the semi-submersible structure (5).

66. A floatable structure as claimed in Claim 65 characterised in that the ballast receiving means (19, 42) extends circumferentially around the main central axis (12).

67. A floatable structure as claimed in Claim 65 or 66 characterised in that the ballast receiving means (19, 42) is radially spaced apart from the main central axis (12).

68. A floatable structure as claimed in any of Claims 65 to 67 characterised in that the ballast receiving means (19, 42) comprises a ballast chamber (19).

69. A floatable structure as claimed in Claim 68 characterised in that a plurality of ballast chambers (19) are located around the main central axis (12).

70. A floatable structure as claimed in any of Claims 65 to 69 characterised in that a means is provided for flooding each ballast chamber (19).

71. A floatable structure as claimed in any of Claims 65 to 70 characterised in that the ballast receiving means (19, 42) comprises a ballast engaging means (42) for receiving ballast members (43).

72. A floatable structure as claimed in Claim 71 characterised in that the ballast engaging means (42) is located beneath the ballast chambers (19).

73. A floatable structure as claimed in any of Claims 46 to 72 characterised in that a secondary buoyancy chamber (34) is located above the primary buoyancy chamber (16) and is isolated from the primary buoyancy chamber (16).

74. A floatable structure as claimed in Claim 73 characterised in that the secondary buoyancy chamber (34) extends above the waterline of the semi-submersible structure (5) when the semi-submersible structure is freely floating.

75. A floatable structure as claimed in Claim 73 or 74 characterised in that the

secondary buoyancy chamber (34) is located to be below the waterline when the semi-submersible structure (5) is urged downwardly in the water by the primary ligature (23).

76. A floatable structure as claimed in any of Claims 46 to 75 characterised in that a plurality of secondary connecting means (65, 66) are provided for connecting respective secondary ligatures (62) extending in a generally downwardly direction from the semi-submersible structure (5) for further anchoring the semi-submersible structure (5) and for limiting movement of the semi-submersible structure (5) from its equilibrium flotation state, the secondary connecting means (65, 66) being spaced apart circumferentially around the main central axis (12) of the semi-submersible structure (5) and radially therefrom.

77. A floatable structure as claimed in Claim 76 characterised in that the secondary connecting means (65, 66) connect the respective secondary ligatures (62) to the semi-submersible structure (5) with the secondary ligatures (62) extending in a generally downwardly direction to corresponding secondary anchorages (69) in the sea bed (25).

78. A floatable structure as claimed in Claim 76 or 77 characterised in that the secondary connecting means (65, 66) are equi-spaced apart circumferentially around the main central axis (12) of the semi-submersible structure (5).

79. A floatable structure as claimed in any of Claims 76 to 78 characterised in that the respective secondary connecting means (65, 66) are located on a common pitch circle.

80. A floatable structure as claimed in any of Claims 76 to 79 characterised in that the respective secondary connecting means (65, 66) are located adjacent a periphery of the semi-submersible structure (5).

81. A floatable structure as claimed in any of Claims 76 to 80 characterised in

that the respective secondary connecting means (65, 66) are located adjacent an outer periphery of the semi-submersible structure (5).

82. A floatable structure as claimed in any of Claims 76 to 81 characterised in that each secondary connecting means (65, 66) comprises a resilient mounting (66) for resiliently connecting the corresponding secondary ligature (62) to the semi-submersible structure (5) for damping oscillating movement of the semi-submersible structure (5) from its equilibrium flotation state about the vertical.

83. A floatable structure as claimed in Claim 82 characterised in that each resilient mounting means (66) comprises a compression spring (66) carrying a mounting member (65) for securing the corresponding secondary ligature (62) thereto so that upward movement of the semi-submersible structure (5) adjacent the resilient mounting means causes compression of the compression spring (66).

84. A floatable structure as claimed in any of Claims 46 to 83 characterised in that a plurality of auxiliary connecting means (28) are provided for connecting respective auxiliary ligatures (29) to the semi-submersible structure (5) for further anchoring and stabilising the semi-submersible structure (5), the auxiliary connecting means (28) being located at spaced apart intervals circumferentially around the main central axis (12) of the semi-submersible structure (15) and radially spaced apart therefrom.

85. A floatable structure as claimed in Claim 84 characterised in that the auxiliary connecting means (28) connect the respective auxiliary ligatures to the semi-submersible structure (5) with the auxiliary ligatures (29) extending in a generally downwardly, radially outward direction to corresponding auxiliary anchorages (30) in the sea bed (25).

86. A floatable structure as claimed in Claim 84 or 85 characterised in that the respective auxiliary connecting means (28) are equi-spaced apart circumferentially around the main central axis (12) of the semi-submersible structure (5).

87. A floatable structure as claimed in any of Claims 84 to 86 characterised in that the respective auxiliary connecting means (28) are located on a common pitch circle.

88. A floatable structure as claimed in any of Claims 84 to 87 characterised in that the respective auxiliary connecting means (28) are located adjacent a periphery of the semi-submersible structure (5).

89. A floatable structure as claimed in any of Claims 84 to 88 characterised in that the respective auxiliary connecting means (28) are located adjacent an outer periphery of the semi-submersible structure (5).

90. A floatable structure as claimed in any of Claims 84 to 87 characterised in that the respective auxiliary connecting means (28) are provided for connecting the corresponding auxiliary ligatures (29) to the semi-submersible structure (5) with the auxiliary ligatures (29) extending in a generally downwardly radially outward direction from the semi-submersible structure (5).

91. A floatable structure as claimed in any of Claims 84 to 90 characterised in that the respective auxiliary connecting means (28) are provided for connecting the auxiliary ligatures (29) to the semi-submersible structure (5) with the respective auxiliary ligatures (29) extending from the semi-submersible structure (5) at an angle to the vertical in the range of 1° to 89°.

92. A floatable structure as claimed in Claim 91 characterised in that the respective auxiliary connecting means (28) are provided for connecting the auxiliary ligatures (29) to the semi-submersible structure (5) with the respective auxiliary ligatures (29) extending from the semi-submersible structure (5) at an angle to the vertical in the range of 60° to 80°.

93. A floatable structure as claimed in Claim 92 characterised in that the

respective auxiliary connecting means (28) are provided for connecting the auxiliary ligatures (29) to the semi-submersible structure (5) with the respective auxiliary ligatures extending from the semi-submersible structure at an angle to the vertical of approximately 70°.

94. A floatable structure as claimed in any of Claims 84 to 93 characterised in that the auxiliary connecting means (28) are located towards the bottom of the semi-submersible structure (5).

95. A floatable structure as claimed in any of Claims 84 to 94 characterised in that the auxiliary connecting means (28) are located for connecting the respective auxiliary ligatures (29) to the semi-submersible structure (5) so that the auxiliary ligatures define a cathenary.

96. A floatable structure as claimed in any of Claims 84 to 95 characterised in that the respective auxiliary connecting means (28) are located at a level above the respective secondary connecting means (65, 66).

97. A floatable structure as claimed in any of Claims 46 to 96 characterised in that an auxiliary buoyancy chamber (70) extends around the secondary buoyancy chamber (34).

98. A floatable structure as claimed in any of Claims 46 to 97 characterised in that the transverse cross-section of the semi-submersible structure (5) when viewed in plan adjacent the average wave height when the semi-submersible structure (5) is urged downwardly in the water by the primary ligature is relatively narrow for minimising resistance to waves.

99. A floatable structure as claimed in any of Claims 46 to 98 characterised in that the semi-submersible structure (5) comprises the primary ligature (23).

100. A floatable structure as claimed in any of Claims 46 to 99 characterised in

that the semi-submersible structure (5) comprises the secondary ligatures (62).

101. A floatable structure as claimed in any of Claims 46 to 100 characterised in that the semi-submersible structure (5) comprises the auxiliary ligatures (29).

102. A floatable structure as claimed in any of Claims 46 to 101 characterised in that a component chamber (37) is located in the semi-submersible structure (5) for accommodating an electrical generator (39) and/or control apparatus for the electrical generator.

103. A floatable structure as claimed in Claim 102 characterised in that the component chamber (37) is located between the primary and secondary buoyancy chambers (16, 34).

104. A floatable structure as claimed in any of Claims 46 to 103 characterised in that the mounting means (45) for mounting the mast (6) on the semi-submersible structure (5) is located above the waterline of the semi-submersible structure (5).

105. A floatable structure as claimed in any of Claims 46 to 104 characterised in that the mounting means (45) for mounting the mast (6) on the semi-submersible structure (5) is located above the waterline of the semi-submersible structure (5) when the semi-submersible structure is urged downwardly by the primary ligature (23) in the water.

106. A floatable structure as claimed in any of Claims 46 to 105 characterised in that the mast (6) is mounted on the semi-submersible structure (5).

107. A floatable structure as claimed in Claim 106 characterised in that the wind turbine (3) is mounted on the mast (6).

108. A floatable structure as claimed in Claim 106 or 107 characterised in that the wind turbine (3) is mounted on the top of the mast (6).

109. A floatable structure as claimed in any of Claims 46 to 108 characterised in that the wind turbine (3) is a horizontal axis wind turbine.

110. A floatable structure as claimed in any of Claims 46 to 108 characterised in that the wind turbine (3) is a vertical axis wind turbine.

111. A floatable structure for locating a wind turbine (3) offshore, the floatable structure comprising a semi-submersible structure (5) having a primary buoyancy chamber (16), and comprising a mounting means (45) located thereon for mounting a mast (6) extending upwardly therefrom for carrying the wind turbine (3) thereon, the semi-submersible structure (5) defining a main geometric central axis (12) and being floatable in an equilibrium flotation state with the main central axis (12) extending generally vertically, and at least two secondary connecting means (65, 66) spaced apart circumferentially around the main central axis (12) and radially therefrom for connecting the semi-submersible structure (5) to respective corresponding secondary ligatures (62) extending generally downwardly from the semi-submersible structure (5) for anchoring the semi-submersible structure (5) and for urging the semi-submersible structure (5) downwardly in the water against an upwardly directed buoyancy force acting on the semi-submersible structure (5) for raising the centre of flotation (26) of the semi-submersible structure (5) for in turn increasing the righting moment acting on the semi-submersible structure (5) for returning the semi-submersible structure (5) to its equilibrium flotation state.

112. A floatable structure as claimed in Claim 111 characterised in that a plurality of the secondary connecting means (65, 66) are provided for connecting a plurality of the respective secondary ligatures (62) extending in a generally downwardly direction from the semi-submersible structure (5) for further anchoring the semi-submersible structure (5), the secondary connecting means (65, 66) being spaced apart circumferentially around the main central axis (12) of the semi-submersible structure (5) and radially therefrom.

113. A floatable structure as claimed in Claim 111 or 112 characterised in that the secondary connecting means (65, 66) are equi-spaced apart circumferentially around the main central axis (12) of the semi-submersible structure (5).

114. A floatable structure as claimed in any of Claims 111 to 113 characterised in that the respective secondary connecting means (65, 66) are located on a common pitch circle.

115. A floatable structure as claimed in any of Claims 111 to 114 characterised in that the respective secondary connecting means (65, 66) are located adjacent a periphery of the semi-submersible structure (5).

116. A floatable structure as claimed in any of Claims 111 to 115 characterised in that the respective secondary connecting means (65, 66) are located adjacent an outer periphery of the semi-submersible structure (5).

117. A floatable structure as claimed in any of Claims 111 to 116 characterised in that each secondary connecting means (65, 66) comprises a resilient mounting (66) for resiliently connecting the corresponding secondary ligature (62) to the semi-submersible structure (5) for damping oscillating movement of the semi-submersible structure (5) from its equilibrium flotation state about the vertical.

118. A floatable structure as claimed in Claim 117 characterised in that each resilient mounting means (66) comprises a compression spring (66) carrying a mounting member (65) for securing the corresponding secondary ligature (62) thereto so that upward movement of the semi-submersible structure (5) adjacent the resilient mounting means causes compression of the compression spring (66).

119. A floatable structure as claimed in any of Claims 111 to 118 characterised in that each secondary connecting means (65, 66) connects the corresponding secondary ligature (23) to the semi-submersible structure with the secondary ligature (62) extending in a generally downwardly direction to corresponding secondary

anchorage (69) in the sea bed (25).

120. A floatable structure as claimed in any of Claims 111 to 119 characterised in that a plurality of auxiliary connecting means (28) are provided for connecting respective auxiliary ligatures (29) to the semi-submersible structure (5) for further anchoring the semi-submersible structure (5), the auxiliary connecting means (28) being located at spaced apart intervals circumferentially around the main central axis (12) of the semi-submersible structure (5) and radially spaced apart therefrom.

121. A floatable structure as claimed in Claim 120 characterised in that the respective auxiliary connecting means (28) are equi-spaced apart circumferentially around the main central axis (12).

122. A floatable structure as claimed in Claim 120 or 121 characterised in that the respective auxiliary connecting means (28) are located on a common pitch circle.

123. A floatable structure as claimed in any of Claims 120 to 122 characterised in that the respective auxiliary connecting means (28) are located adjacent a periphery of the semi-submersible structure (5).

124. A floatable structure as claimed in any of Claims 120 to 123 characterised in that the respective auxiliary connecting means (28) are located adjacent an outer periphery of the semi-submersible structure.

125. A floatable structure as claimed in any of Claims 120 to 124 characterised in that the auxiliary connecting means (28) are provided for connecting the corresponding auxiliary ligatures to the semi-submersible structure (5) with the auxiliary ligatures (29) extending in a generally downwardly, radially outward direction from the semi-submersible structure (5).

126. A floatable structure as claimed in any of Claims 120 to 125 characterised in that the respective auxiliary connecting means (28) are provided for connecting the

auxiliary ligatures (29) to the semi-submersible structure (5) with the respective secondary ligatures (29) extending from the semi-submersible structure (5) at an angle to the vertical in the range of 1° to 89°.

127. A floatable structure as claimed in any of Claims 120 to 126 characterised in that the respective auxiliary connecting means (28) are provided for connecting the auxiliary ligatures (29) to the semi-submersible structure with the respective auxiliary ligatures (29) extending from the semi-submersible structure (5) at an angle to the vertical in the range of 60° to 80°.

128. A floatable structure as claimed in any of Claims 120 to 127 characterised in that the respective auxiliary connecting means (28) are provided for connecting the auxiliary ligatures (29) to the semi-submersible structure (5) with the respective secondary ligatures (29) extending from the semi-submersible structure (5) at an angle to the vertical of approximately 70°.

129. A floatable structure as claimed in any of Claims 120 to 128 characterised in that the auxiliary connecting means (28) are located towards the bottom of the semi-submersible structure (5).

130. A floatable structure as claimed in any of Claims 120 to 129 characterised in that the auxiliary connecting means (28) are located for connecting the respective auxiliary ligatures (29) extending from the semi-submersible structure (5) to define a cathenary.

131. A floatable structure as claimed in any of Claims 120 to 130 characterised in that each auxiliary connecting means (28) connects the corresponding auxiliary ligature (29) to the semi-submersible structure to extend in a generally downwardly radially outward direction to a corresponding auxiliary anchorage (30) in the sea bed (25).

132. A floatable structure as claimed in any of Claims 111 to 131 characterised in

that the semi-submersible structure (5) comprises the secondary ligatures (62).

133. A floatable structure as claimed in any of Claims 111 to 132 characterised in that the semi-submersible structure (5) comprises the auxiliary ligatures (29).

134. A wind power energy converter for converting wind energy to usable power comprising the semi-submersible structure (5) as claimed in any of Claims 46 to 133, the semi-submersible structure (5) being anchored by the primary ligature (23) extending in a generally downwardly direction, and being urged downwardly in the water by the primary ligature (23) against the upward direction of the buoyancy force acting on the semi-submersible structure (5), for raising the centre of flotation (26) of the semi-submersible structure (5) for in turn increasing the righting moment acting on the semi-submersible structure (5) for returning the semi-submersible structure (5) to its equilibrium flotation state, a mast (6) extending upwardly from the semi-submersible structure (5), and a wind turbine (3) mounted on the mast (6) for providing usable power.

135. A wind energy converter as claimed in Claim 134 characterised in that an electrical generator (39) is operably coupled to the wind powered turbine (3) for generating electricity.

136. A wind farm comprising a plurality of the wind energy converters as claimed in Claim 134 or 135 for converting wind energy to usable energy, the wind energy converters (1) being located at spaced apart intervals offshore.

137. A wind farm as claimed in Claim 136 characterised in that the wind energy converters (1) are located in a plurality of spaced apart rows (51), each row comprising a plurality of wind energy converters (1).

138. A wind farm as claimed in Claim 136 or 137 characterised in that the wind energy converters (1) of alternate rows (51) are offset from the wind energy converters (1) of their adjacent rows (51).

139. A wind farm as claimed in any of Claims 136 to 138 characterised in that the wind energy converters (1) of alternate rows (51) are located substantially halfway between the wind energy converters (1) of their adjacent rows (51) in an offset state.

140. A wind farm as claimed in any of Claims 136 to 139 characterised in that the rows of wind energy converters (1) are equi-spaced apart from each other.

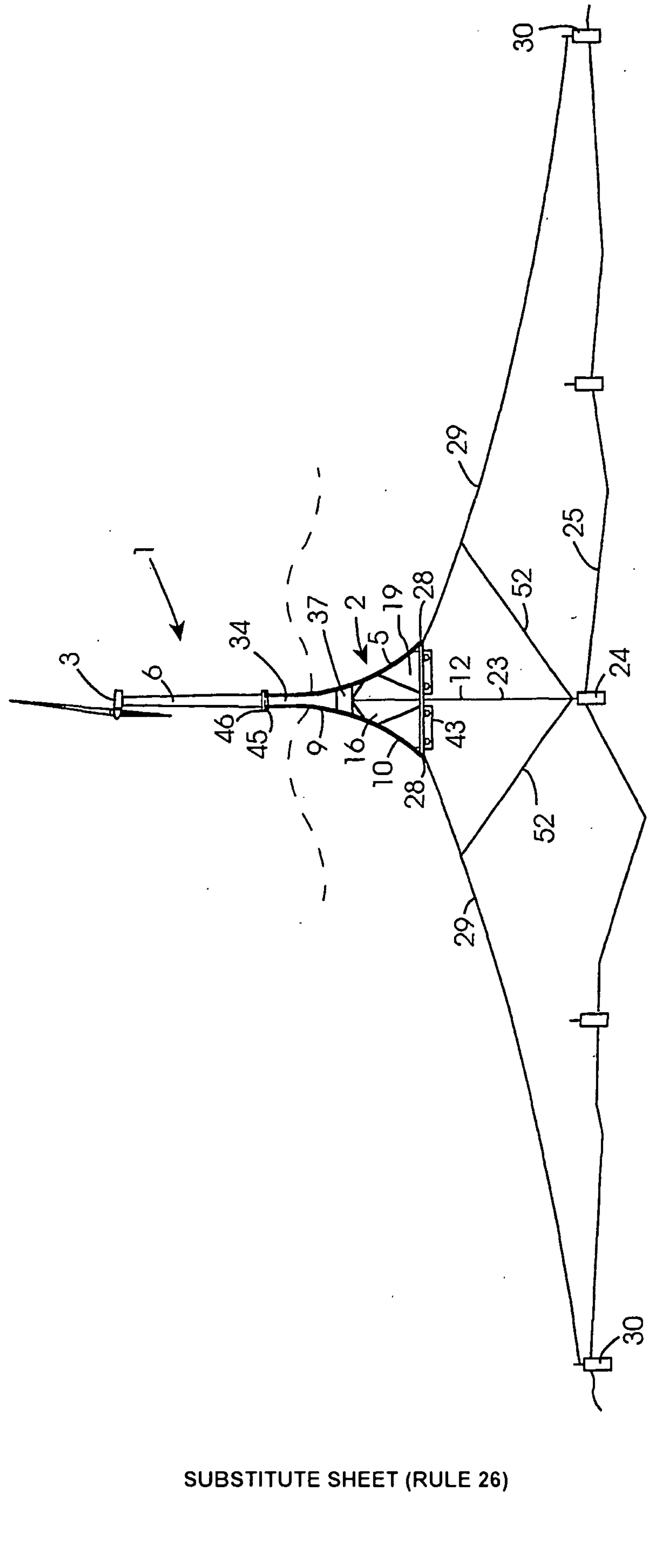


Fig. 1

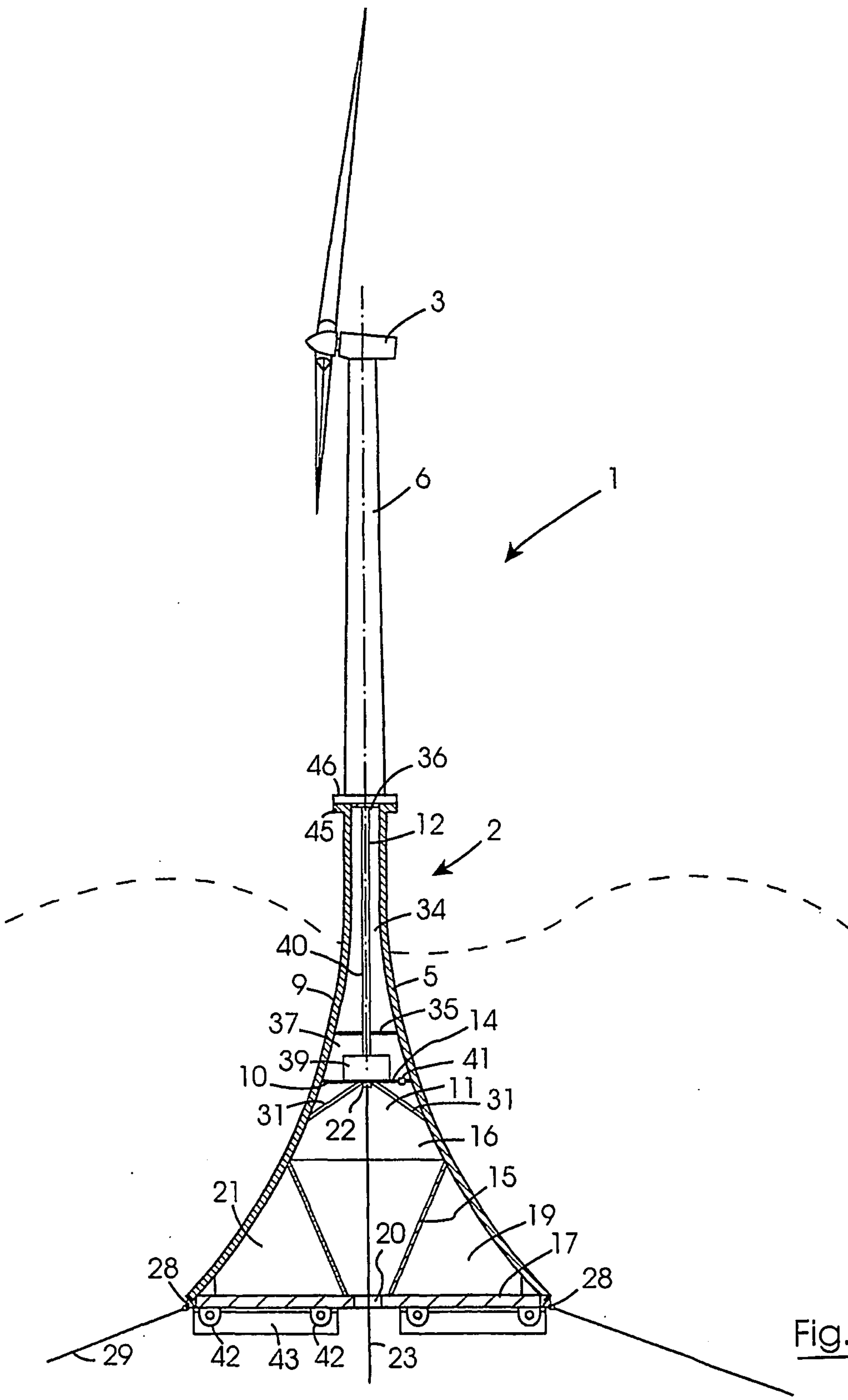

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Fig. 2

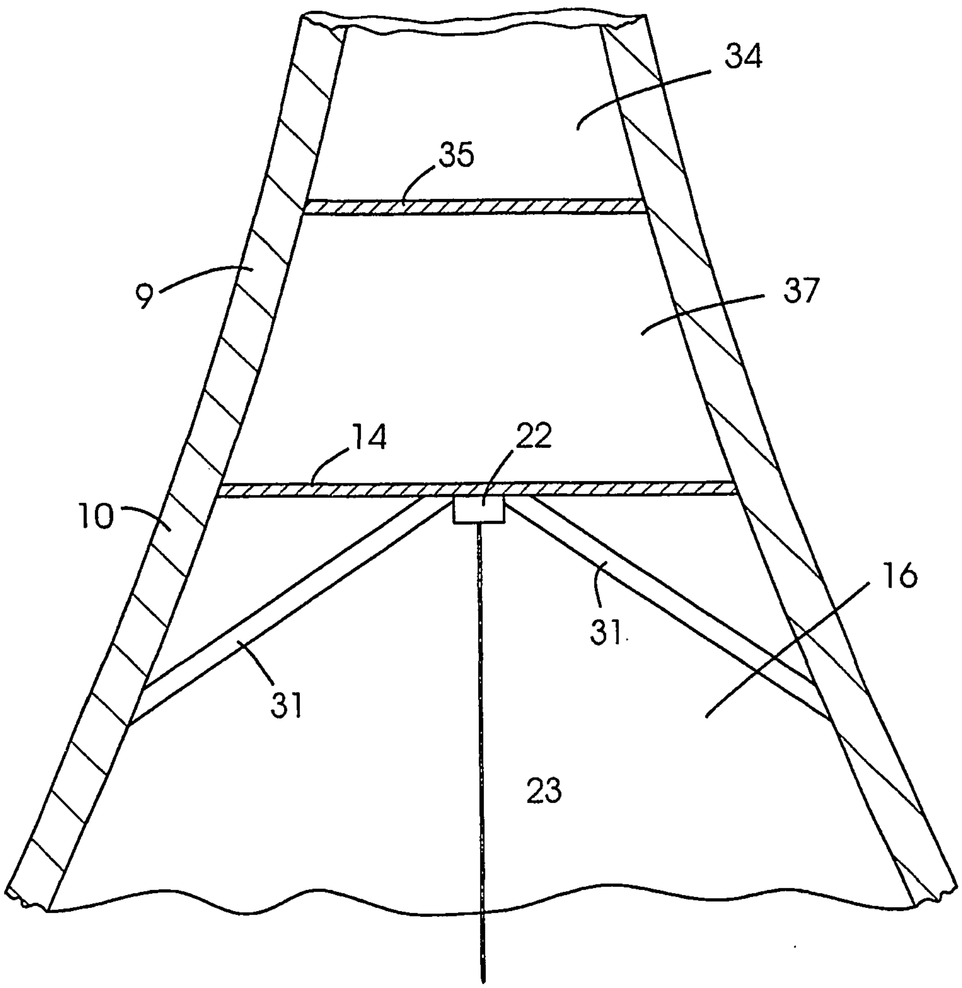

Fig. 3

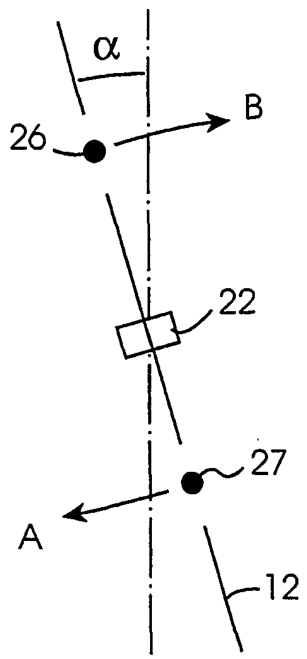

Fig. 7

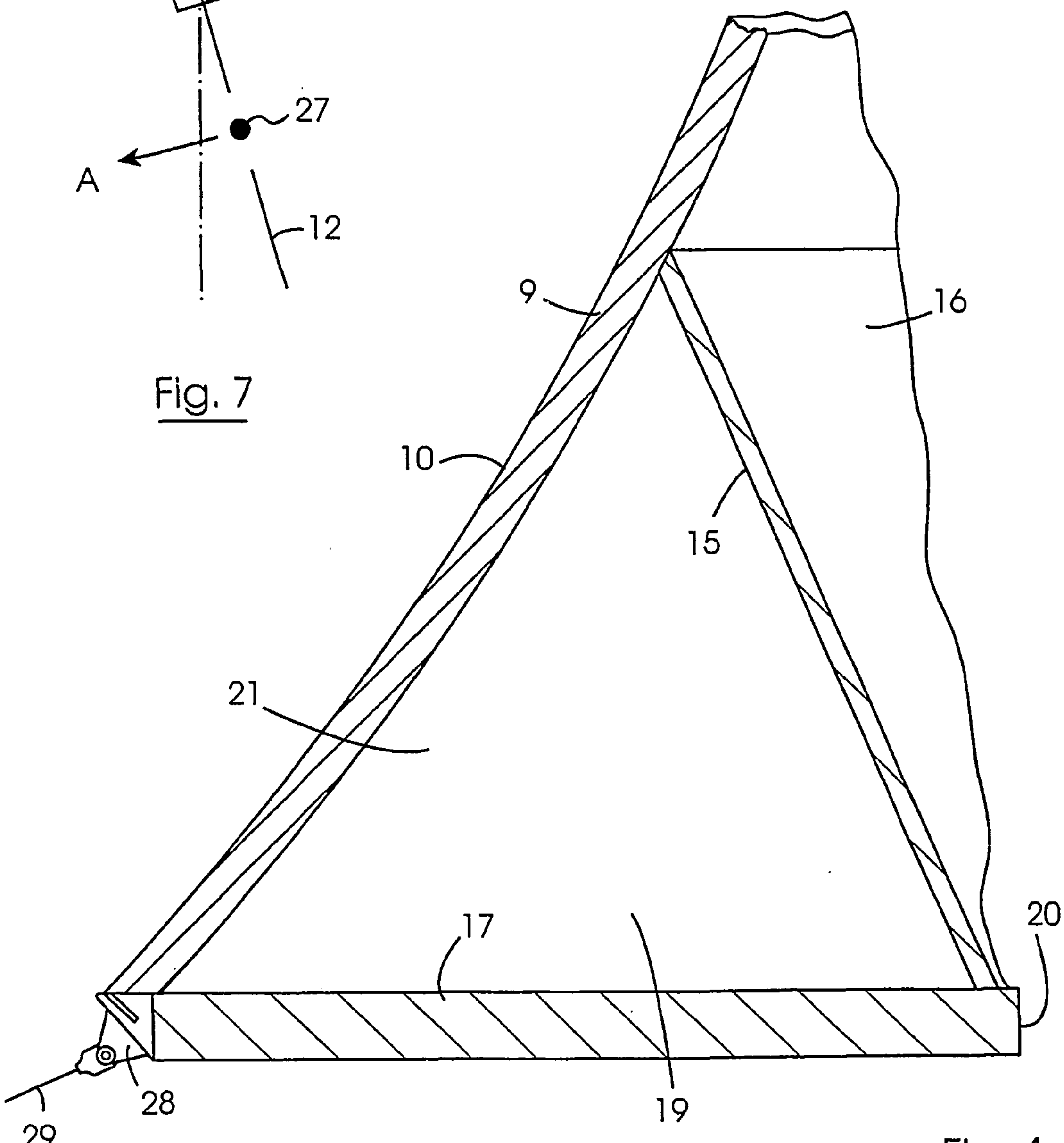

Fig. 4

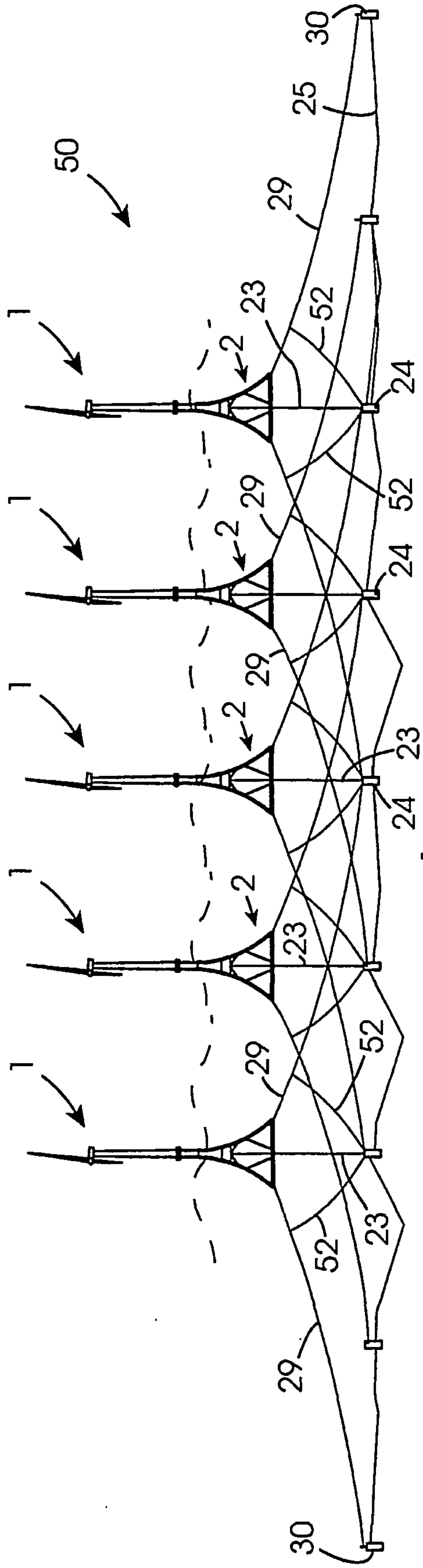

Fig. 5

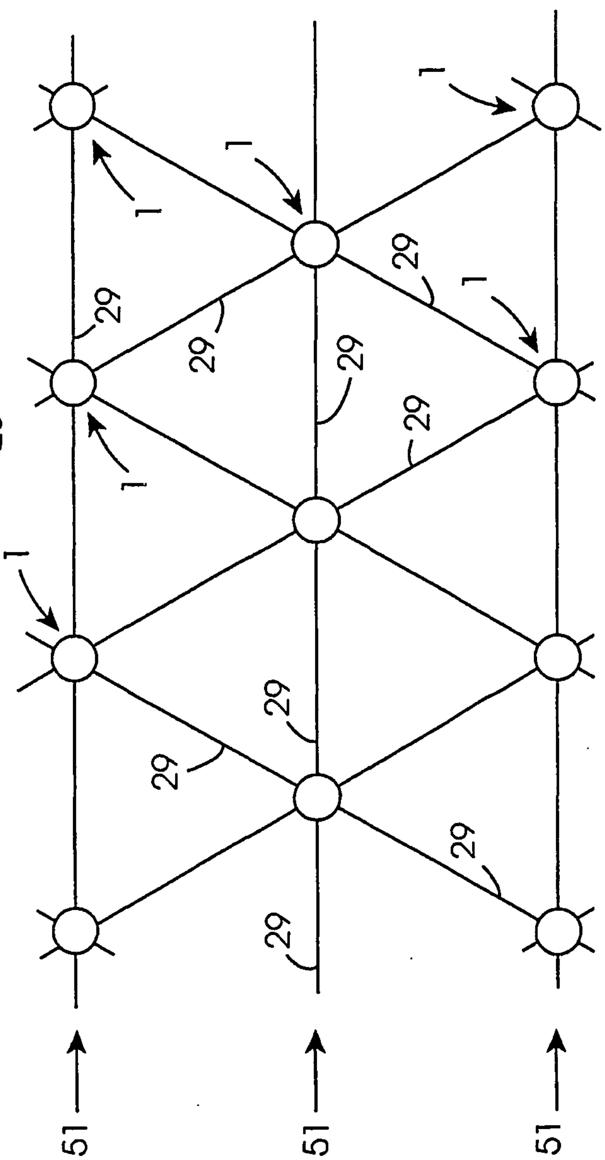

Fig. 6

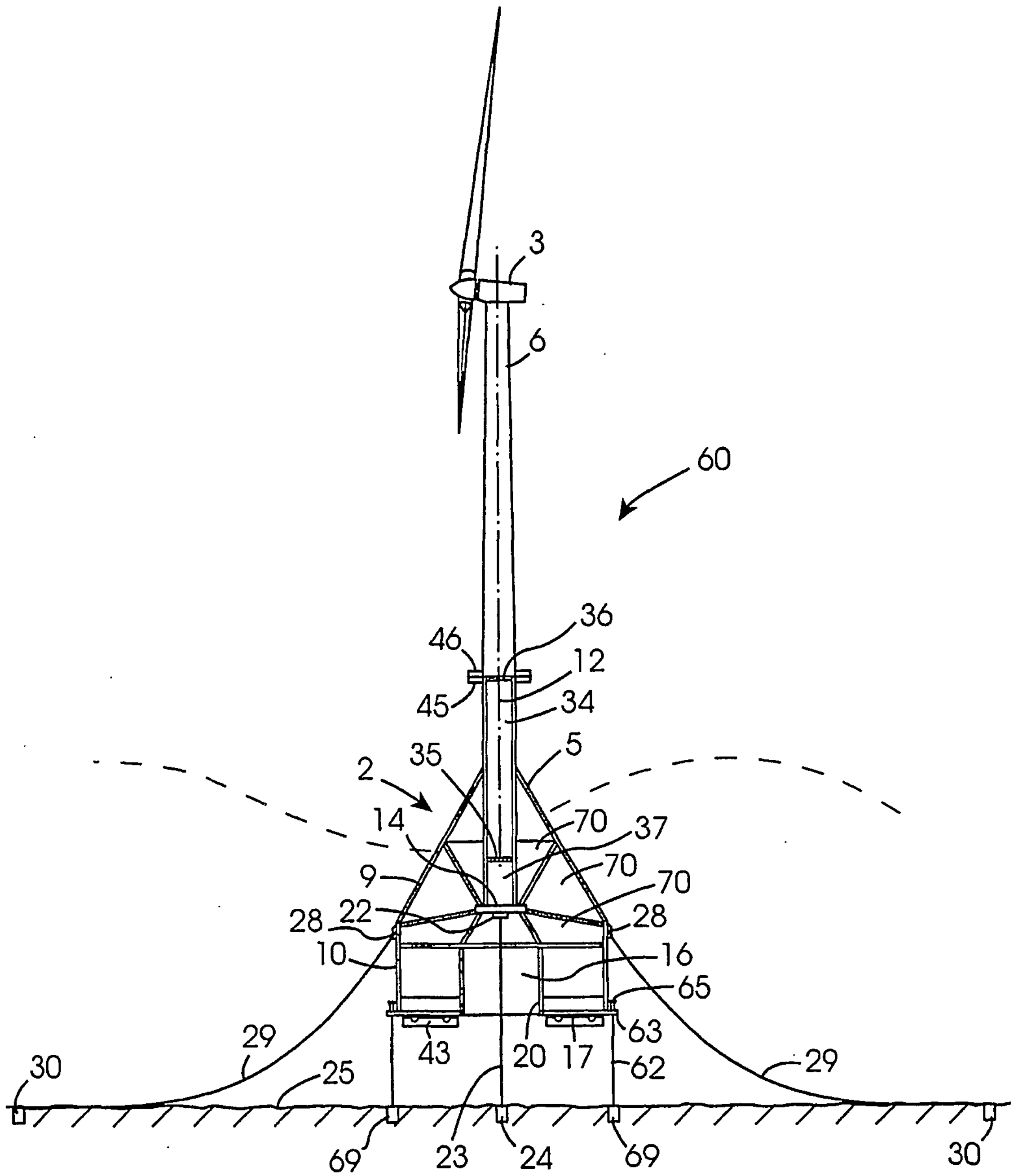
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Fig. 8

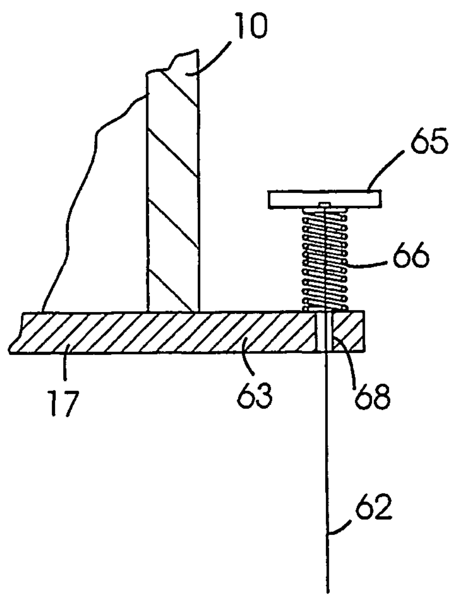

Fig. 10

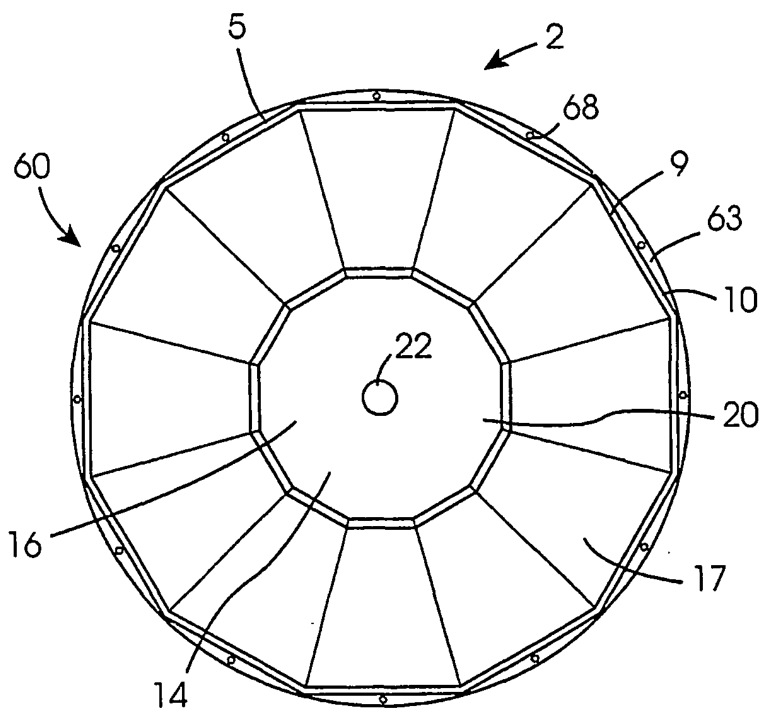

Fig. 9

INTERNATIONAL SEARCH REPORT

International Application No
PCT/IE 01/00097

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 F03D11/04 B63B21/50

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 F03D B63B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, INSPEC, COMPENDEX

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	FR 2 507 146 A (TIM TECH IND MINIERES) 10 December 1982 (1982-12-10)	1-135
Y	page 2, line 32 -page 3, column 7 page 3, line 15 - line 33 page 4, line 13 - line 22 page 4, line 33 -page 5, line 1 page 5, line 16 - line 26 page 6, line 14 - line 16; figure 8 page 8, line 3 - line 7 page 9, line 17 - line 31 page 10, line 17 - line 22 page 13, line 11 - line 12 page 14, line 7 - line 13 ---	136-140

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
19 October 2001	09/11/2001

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Criado Jimenez, F

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INTERNATIONAL SEARCH REPORT

International Application No
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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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